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JOURNAL OF PALEONTOLOGY

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ORDOVICIAN CEPHALOPODS FROM THE BIGHORN MOUNTAINS OF WYOMING

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ABSTRACT—Few cephalopods have been described previously from the Bighorn formation of the Bighorn Mountains, but the following nautiloid genera are now known to occur there: *Endoceras, Cyclendoceras, Billingsites, Spyroceras, Metaspyroceras, Ephippiorthoceras, Lambeoceras, Diestoceras, Neumatoceras, Richardsonoceras, Winnipegoceras, Exomegoceras* [n. gen.], *Digenuoceras, Apsidoceras, Characterina, Actinoceras, Paractinoceras, Armenoceras, Selkirkoceras*, and *Huronia*. Representatives of most of these are illustrated and described, and it is concluded that the fauna is closely related to those known from the Lander sandstone of western Wyoming, the Whitewood dolomite of the Black Hills, the Fremont limestone of Colorado, the Stewartville and the Maquoketa formations of the Upper Mississippi Valley, the Red River formation of Manitoba, and equivalent beds in Anticosti Island, Arctic Canada, and Greenland, as well as the Lyckholm of the eastern Baltic area and the Drummuck group of southern Scotland.

THE BIGHORN formation of Wyoming, Montana, and Idaho is part of a widespread marine deposit that extends from the American Arctic through the Rocky Mountains into northern Mexico. Although numerous studies of the fossils contained in this deposit have been made by Foerste, Miller, Troedsson, and others, the abundant fauna of the Bighorn formation in the Bighorn Mountains has never been given detailed consideration.

During the summer of 1935 the senior author, accompanied by W. M. Furnish, visited the northern portion of the Bighorn Mountains and obtained a variety of cephalopods from the extensive exposures of the Ordovician strata there. Five years later, the junior author spent several weeks in the same area and collected a representative fauna from the Bighorn formation along the western flank of the range. We are indebted to Ranger Les Shoemaker and Messrs. Ray and Del Jackson for general assistance in the field, and to Messrs. A. G. Unklesbay and Howard Webster for help with the preparation of the illustrations which accompany this report.

The Bighorn formation was named by Darton in 1904 from outcrops on the eastern flank of the Bighorn Mountains. The term was applied to Ordovician strata which are almost 300 feet thick. In the type locality the formation consists of a basal sandstone averaging 25 to 30 feet in thickness, some 150 feet of massive dolomite, and an upper thin-bedded dolomite member 75–100 feet thick. These beds are underlain by the Upper Cambrian Deadwood formation and are overlain by the Madison limestone of Mississippian age.

In the northwestern portion of the Bighorn Mountains, where most of our speci-

mens were collected, the Bighorn formation consists of a lower massive dolomite overlain by a thin-bedded dolomitic member. A basal sandstone apparently is not present in this area, and at the only locality where the Cambro-Ordovician contact was observed massive dolomite rests directly on the Deadwood. However, a very few of the numerous fossils obtained from talus blocks are composed of arenaceous dolomite, which seems to suggest that locally the basal portion of the formation here may be clastic, as it is in other places.

It should perhaps be mentioned that the great majority of the specimens on which the present report is based came from (1) Medicine Mountain, just north of the road from Sheridan to Lovell, (2) along Wallrock Creek just east of Hunt Mountain, about 10 miles southeast of Medicine Mountain, and (3) Copemans Tomb, about 11 miles southeast of Hunt Mountain. At all three of these localities there are extensive accumulations of large talus boulders of dolomite at the base of high cliffs, which are so characteristic of the massive dolomite member of the Bighorn formation over most of its area of outcrop. Almost all of our specimens were obtained from the talus rather than the cliffs.

In 1932 Miller described a large and varied cephalopod fauna from the Bighorn formation in the Wind River Mountains of west-central Wyoming. Most of his specimens came from a thin basal sandstone, the Lander sandstone, and only two specimens (*Spyroceras rarum* and *Allumettoceras?* sp.) were found in the dolomite. In 1935 Foerste published a second report on Bighorn cephalopods, and the majority of his specimens also came from the Lander sandstone in the Wind River Mountains. However, he included a few specimens from (1) the basal sandstone of the Bighorn formation along Bear Trap Creek between the headwaters of Beaver Creek and the nearest part of the North Fork of Powder River, on the eastern flank of the Bighorn Range, and (2) from talus boulders of the massive Bighorn dolomite on Medicine Mountain. Those from the former locality he called *Charactocerina kirki* and *Neumatoceras?* sp.; those from the latter, *Billingsites multicameratus, Digenuoceras* cf. *D. latum, Ephippiorthoceras dowlingi, Neumatoceras gibberosum, N. nutans, Paractinoceras canadense,* and *Spyroceras rarum.* As early as 1928, Foerste had described *Huronia occidentale* from the Bighorn formation in the Bighorn Mountains, and in the following year he mentioned the occurrence of *Cyclendoceras* in the same general horizon and locality. We are now able to increase to 20 the number of nautiloid genera known from the Bighorn formation in the Bighorn Mountains, and altogether a total of 33 genera of cephalopods have been found to occur in the formation (table 1).

When Darton originally described the Bighorn formation in 1904, he referred it to the late Ordovician. However, in 1906 he discussed its age more fully and on the advice of Ulrich concluded that the massive dolomite member is of lower Galena-Trenton age but that the upper thin-bedded dolomite should be regarded as Richmond. More recently Kirk has suggested that the massive dolomite is also referable to the "Cincinnatian (used in the sense of being pre-Richmond, post-Trenton)," and Miller and Foerste have also placed the entire formation in the Upper Ordovician. Kay, however, apparently believes that it belongs in the Middle Ordovician.

As a matter of fact, it does not seem particularly difficult to correlate the Bighorn and the closely related Whitewood formations with beds to the north in Canada and Greenland and to the south in United States and Mexico, but correlations to the east are much less certain. That is, as evidenced by table 1, the cephalopods of the Red River formation of Manitoba and equivalent beds in Anticosti Island, northern Canada, and Greenland are quite similar to those of the Bighorn and the Whitewood, as are the few known from the Fremont limestone of Colorado. It seems, however, that the so-called "Arctic fauna" that is characteristic of these beds has an appreciable stratigraphic range, and it is therefore not possible to determine with certainty just which portions of the Bighorn formation are equivalent to each of the three Ordovician formations of Anticosti Island or to each of the three members of the Red River formation of Manitoba. Also the relationship with the cephalopod-bearing portion of the White-

TABLE 1.—CHIEF DISTRIBUTION OF CEPHALOPOD GENERA REPRESENTED IN BIGHORN FORMATION

Genus \ Horizon and locality	Fremont of Colorado	Whitewood of Black Hills	Stewartville of Iowa-Minnesota	Maquoketa of Iowa	Richmond of Indiana-Ohio	English Head of Anticosti Island	Vauréal of Anticosti Island	Ellis Bay of Anticosti Island	Red River of Manitoba	Nelson-Shamattawa of Hudson Bay	"Red River" of Foxe Land	Limestone of Frobisher Bay	Cape Calhoun of Greenland	Lyckholm of East Baltic
Actinoceras						×	×	×	×	×		×	×	
Allumettoceras														×
Apsidoceras						×	×	×		×			×	
Armenoceras				×		××	××		×	×			×	
Beloitoceras				×		××	××	×				×		?
Billingsites					×	×	×	×	×	×				×
Charactocerina									×					
Cyclendoceras		×		×					×		×			
Cyrtogomphoceras	×	×							×	×	×	×	×	?
Diestoceras	×	×			×	×	×	×	×	×	×	×	×	×
Digenuoceras									×					
Dowlingoceras									×					?
Endoceras		×	×	×		×		×	×	×	×	×	×	×
Ephippiorthoceras		×	×	×		×	×	×	×	×	×	×	×	
Exomegoceras														
Geisonocerina		?												
Huronia									×	×			×	
Kionoceras				×		×						×		
Kochoceras									×	×		×	×	?
Lambeoceras		?	×		×				×		?		×	
Landeroceras														
Metaplectoceras	·								×					
Metaspyroceras														×
Neumatoceras	×								?	?		?		
Oncoceras						×		?				?		
Paractinoceras									×					
Richardsonoceras	?													
Selkirkoceras									×					
Spyroceras		×		×		×	×	×	×	×		×	×	×
Tripterocerina														
Whitfieldoceras												×		
Wilsonoceras		×							×					
Winnipegoceras		×							×			×		?

head formation of Gaspé Peninsula is not clear—that formation has yielded representatives of *Apsidoceras*, *Beloitoceras*, *Diestoceras*, *Metaspyroceras*, *Neumatoceras*, and *Spyroceras*.

In the Upper Mississippi Valley both the Stewartville and the Maquoketa formations contain faunas which resemble that of the Bighorn. The Stewartville is lithologically similar to the Bighorn and like it carries *Receptaculites* and *Halysites*, as well as a cephalopod fauna which is related to that of the Bighorn but may be somewhat more primitive. In addition to the genera listed in table 1, *Probillingsites* and *Westonoceras* are known from the Stewartville; the former is presumably the ancestor of *Billingsites* and the latter occurs in the Eden (Southgate shale of Ohio) as well as in equivalents of the Bighorn. *Endoceras* and *Ephippiorthoceras*, which are common to the Stewartville and the Bighorn, are of little value for precise correlation; but *Lambeoceras* is not known to occur below the Stewartville and the Bighorn, and it has been found well up in the Richmond at Richmond, Indiana.

Typically the Stewartville is separated from the Maquoketa by about 30 feet of thin-bedded dolomite known as the Dubuque formation. This dolomite contains few cephalopods, but the overlying Maquoketa has yielded a considerable variety of

nautiloids representing 13 genera: *Geisonoceras*, *Polygrammoceras*, *Deiroceras*, *Sactoceras*, *Charactoceras*, *Deckeroceras*, and those listed in table 1. The similarity of the fauna of the Maquoketa to that of the Bighorn is probably all the more significant because the formations are lithologically dissimilar, and therefore their faunas, even if precisely contemporaneous, might well be quite different.

Of the few cephalopods described from the typical Richmond strata of Indiana and Ohio, three rather characteristic genera are known to occur also in the Bighorn and related strata, and *Charactoceras* of the Richmond is closely akin to *Charactocerina* of the Bighorn. Furthermore, several genera of nautiloids are common to the Lyckholm of the eastern Baltic area and the Bighorn and two (*Neumatoceras* and *Diestoceras*) to the Bighorn and the Drummuck group of southern Scotland.

The data summarized in the preceding paragraphs seem to support the previously recognized conclusion that the Bighorn, Whitewood, Red River, and equivalent strata are of Upper Ordovician age. The relation between the Stewartville and these beds will not be entirely clear until the fauna of that formation has been studied in detail, but it seems probable that the Stewartville is not very much older than the Bighorn and should tentatively be placed in the Upper Ordovician.

SYSTEMATIC PALEONTOLOGY

ENDOCERAS spp.

The genus *Endoceras* is abundantly represented in the Bighorn formation at several localities in the Bighorn Mountains. However, it is difficult to collect complete specimens, and, furthermore, as is well known, it is almost impossible to recognize species in this ubiquitous genus. That is, there is much variation within the genus and few diagnostic characters by means of which to differentiate species. Some of the specimens obtained show that the phragmacone attained a diameter of at least 125 mm. and that the number of camerae in a length equal to the diameter of the conch ranges from 3 to 13.

Occurrence.—Representatives of this genus have been found in the Ordovician and Silurian rocks all over the world. In the Bighorn Mountains they occur in both the arenaceous and the dolomitic members of the Bighorn formation. Fragmentary specimens were found at essentially all localities where the formation was studied, particularly near Hunt and Medicine mountains and in the vicinity of Copemans Tomb, all of which are in the northern half of the Bighorn Mountains.

Repository.—State University of Iowa, 2860–2862.

CYCLENDOCERAS spp.

Cyclendoceras, which is abundant in the Lander sandstone of the Wind River Mountains and in the Whitewood dolomite of the Black Hills, is rather sparingly represented in the Ordovician of the Bighorn Mountains, though its occurrence there was noted some time ago by Foerste (1929, p. 152). Our collections contain only four fragmentary representatives of this genus, which, however, seem to represent two distinct types. That is, one of our specimens bears small closely spaced annulations about like those of *C. costilliferum* Miller of the Lander sandstone, whereas the other three have moderately large and prominent annulations like those of *C. abundum* Miller of the Lander sandstone and the Whitewood dolomite. Unfortunately all four of our specimens represent such small portions of the conch that it is not possible to identify them specifically.

Cyclendoceras was originally based on specimens from the Trenton of New York, but it has since been found to be abundant in the Bighorn and Whitewood formations of northwestern United States and in the Red River formation of Manitoba and equivalent beds in Arctic Canada. It appears to be limited stratigraphically to the Middle and Upper Ordovician, but it is widespread geographically, being known from Europe and Asia as well as North America.

Occurrence.—Two of the three apparently conspecific specimens in our collection came from the Bighorn dolomite on Copemans Tomb, whereas the other two specimens (representing two species) were found on Hunt Mountain; both of these prominences are in the northern part of the Bighorn Mountains.

Repository.—State University of Iowa, 2863–2865.

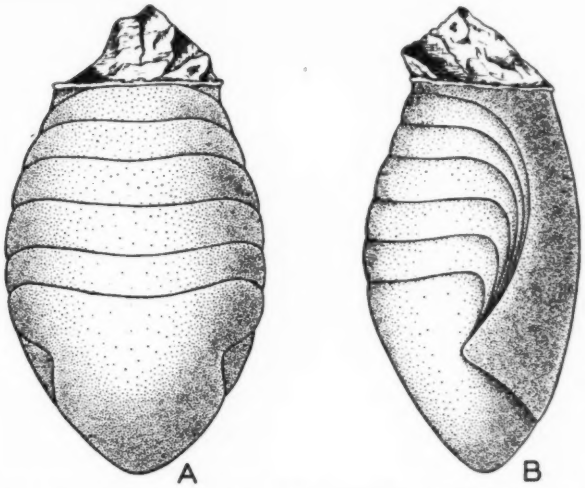

FIG. 1—*Billingsites multicameratus* Miller?, somewhat restored, ×1. Based on two specimens from the Bighorn formation on Medicine Mountain in the northern Bighorn Mountains.

BILLINGSITES MULTICAMERATUS Miller?
Text figure 1

?Billingsites n. sp. MILLER, *1930*, Am. Jour. Sci., ser. 5, vol. 20, p. 200.
?Billingsites multicameratus MILLER, *1932*, Connecticut Acad. Arts and Sci. Trans., vol. 31, pp. 243–244, pl. 10, figs. 6–8.
?Billingsites multicameratus, MILLER, *1932*, Iowa Univ. Studies Nat. Hist., vol. 14, no. 4, p. 27.
Billingsites cf. *B. multicameratus*, FOERSTE, 1935, Denison Univ., Sci. Labs., Bull., vol. 30, p. 10.
Billingsites multicameratus, FOERSTE, *1935*, *idem*, vol. 30, pp. 21–22, pl. 1, fig. 6.

We have two representatives of *Billingsites* that are probably conspecific. However, both of them are only moderately well preserved and appear to be somewhat distorted. In general physiognomy they seem to resemble *B. multicameratus* Miller rather closely, and all of their characters that can be determined with certainty clearly indicate a relationship to that species. However, the larger of our specimens attains a somewhat greater size than does the holotype of *B. multicameratus*. That is, near its midlength its maximum height measures about 28 mm. and its maximum width about 35 mm., whereas corresponding measurements of the holotype are about 27 mm. and 31.5 mm., respectively. The smaller of our specimens is somewhat weathered, but it appears to have been of essentially the same size as the holotype. The adapical end of this smaller specimen resembles that of the holotype very closely, but the adapical end of our larger specimen is incomplete. The general shape of the conch and the nature of the sutures are elucidated by the accompanying illustrations.

Occurrence.—This species was originally described from the Lander sandstone of the Wind River Mountains in west-central Wyoming. In 1935, apparently with some hesitation, Foerste referred to it a rather small fragment from the Bighorn dolomite of Medicine Mountain, the same horizon and locality from which both of our specimens came.

Repository.—State University of Iowa, 2866 and 2867.

SPYROCERAS WYOMINGENSE Miller?
Plate 75, figure 6

?Spyroceras n. sp., MILLER, *1930*, Am. Jour. Sci., ser. 5, vol. 20, p. 200.
?Spyroceras wyomingense MILLER, *1932*, Connecticut Acad. Arts and Sci. Trans., vol. 31, pp. 253–254, pl. 12, fig. 3.

Three specimens in our collections seem to resemble the holotype of this species but are somewhat larger. The largest of them attains a maximum diameter of at least 40 mm., and the smallest has a minimum diameter of some 25 mm. The conch is straight, is expanded orad at an angle of about 10°, and is almost circular in cross section but appears to be slightly depressed dorsoven-

trally. It bears prominent subangular transverse annulations, which are much smaller than the intermediate rounded grooves and rise almost 3 mm. above them where the diameter of the conch is about 30 mm. Some three or four of these annulations occur in a distance equal to the diameter of the conch. Also, the surface of the test bears longitudinal lirae, which alternate in prominence. These lirae appear to be about equally developed on all sides of the conch and on the annulations and in the grooves.

Septa are only slightly convex apicad and are simple saucer-shaped disks. Sutures are located midway between transverse annulations and are parallel to them. Siphuncle is small, circular in cross section, and central (or nearly so) in position. Where the diameter of the conch measures about 30 mm., that of the siphuncle measures only about 2.5 mm.

Remarks.—The relatively small size of the holotype of this species may of course be readily explained by assuming that it represents only the adapical portion of the conch. Clearly this species belongs in the so-called "*bilineate* group," which Foerste (1932, p. 95) recognized within the genus *Spyroceras*.

Occurrence.—All three of the specimens under consideration came from the Bighorn dolomite in the northern portion of the Bighorn Mountains. One of them was found on Medicine Mountain, the other two along Wallrock Creek just east of Hunt Mountain.

Repository.—State University of Iowa, 2868 (figured specimen) and 2869 (two unfigured specimens).

METASPYROCERAS SUBCLAVATUM
Miller and Carrier, n. sp.
Plate 75, figure 5

The holotype of this species is a well-preserved internal mold of much of the phragmacone and essentially all of the living chamber. Its length, measured along the lateral zone, is about 153 mm., of which about 103 mm. represent phragmacone and about 50 mm. living chamber. The phragmacone is almost straight, but the living chamber is considerably curved, so that the dorsal profile is concave and the ventral convex. The holotype appears to be slightly distorted, but it is broadly elliptical in cross section, as it is compressed laterally. Near the adapical end of the specimen, the height and width of the conch, measured along a septum, are about 32 mm. and 27.5 mm., respectively. The maximum size of the conch is attained somewhat apicad of the adoral end of the phragmacone, and at the antepenultimate septum the holotype is about 37.5 mm. high and about 30.5 mm. wide. Comparable measurements near the adoral end of the specimen are about 28.5 mm. and 25 mm., respectively. The extreme adoral end of the holotype is incomplete, but it appears to be slightly expanded.

Throughout its entire length, the holotype bears prominent subangular transverse annulations, which rise some 2 mm. above the intermediate rounded grooves. For the most part these annulations are about equally spaced and are some 12 mm. apart, but the two adoral grooves (measured from crest to crest) are each only about 10 mm. wide. In the adoral half of the living chamber of the holotype, the annulations are rounded, but their shape may have been altered during preservation. A partial external mold of the holotype shows that the annulations are much more nearly angular on the exterior of the test than on the internal mold, and that the surface of the test bears longitudinal lirae which are about 2 mm. apart near the midlength of the specimen.

The septa are only moderately convex apicad, and the sutures are essentially straight and directly transverse. Throughout most of the length of the phragmacone,

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EXPLANATION OF PLATE 75

All from talus boulders of Bighorn dolomite in the northern portion of the Bighorn Mountains. Figures *1*, *5*, and *6* from Medicine Mountain, *2–4* from Hunt Mountain.

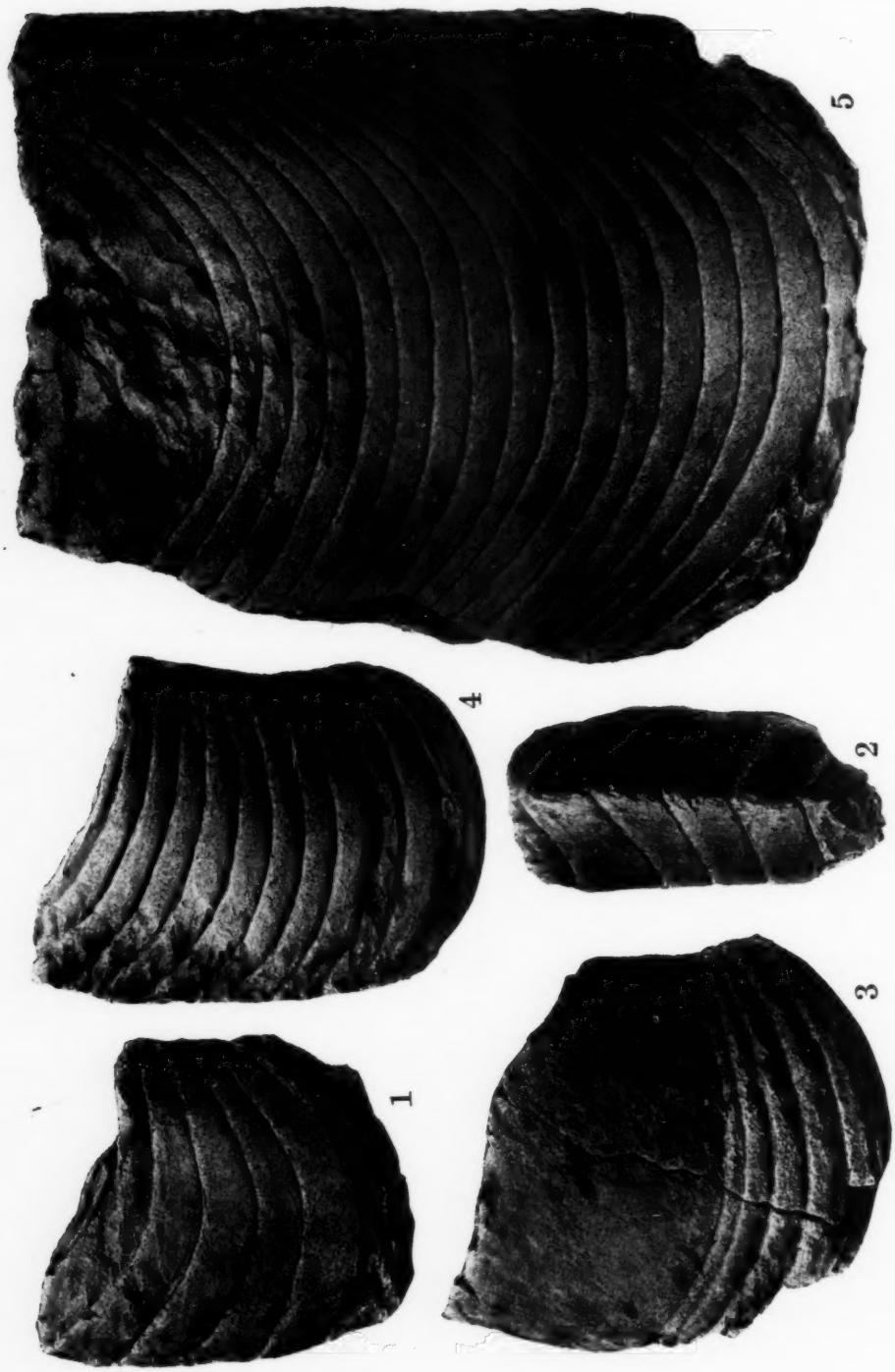
FIGS. *1*—*Actinoceras* sp. Dorsal view of an internal mold, ×⅔. (p. 544)

2–4—*Selkirkoceras tyndallense* Foerste. Three views of a hypotype, ×⅔. (p. 546)

5—*Metaspyroceras subclavatum* Miller and Carrier, n. sp. Lateral view of the holotype, ×⅔. (p. 536)

6—*Spyroceras wyomingense* Miller? Enlargement of a ventrolateral? portion of the test, showing the ornamentation where the conch is some 30 mm. in diameter, ×1¾. (p. 535)

Miller and Carrier, Ordovician Cephalopods



Miller and Carrier, Ordovician Cephalopods

the sutures lie in the center of the grooves between the annulations and are therefore equally spaced. However, the adoral suture is situated slightly apicad of the center of an annulation, and the adoral camera is therefore very short. The siphuncle is small, circular (or nearly so) in cross section, and is located distinctly ventrad of the center of the conch. Near the adoral end of the phragmacone, the siphuncle is about 2.5 mm. in diameter and is about 7 mm. from the venter and about 22.5 mm. from the dorsum.

Remarks.—Three paratypes of this species are available for study. They resemble the holotype very closely but are less nearly complete. It should, however, be noted that one of them is slightly larger than the holotype, and that all of them are somewhat curved, as is the holotype.

Superficially this species resembles *Metaspyroceras geronticum* (Foerste and Savage) of the Shamattawa limestone just south of Hudson Bay. However, the specimen which should be regarded as the holotype of that species is essentially straight and has relatively closely spaced annulations, which become oblique on the living chamber. One of the three type specimens of *M. geronticum* is slightly curved, as are such similar forms as *M.? nicolleti* (Clarke) and *M. wisconsinense* Foerste, both of the Platteville limestone of the Upper Mississippi Valley.

Some time ago, Foerste (1935, p. 10) stated that *Spyroceras rarum* Miller occurs at Medicine Mountain in the northern part of the Bighorn Mountains. The holotype of that species, which came from the massive portion of the Bighorn dolomite in the Wind River Mountains, resembles *M. subclavatum* but has more closely spaced annulations. Nevertheless, it may well be that the specimen from the Bighorn Mountains which was studied by Foreste is conspecific with the above-described form.

M. subclavatum is not a typical representative of the genus *Metaspyroceras* for (1) its conch is compressed laterally rather than depressed dorsoventrally, (2) both the sutures and annulations are directly transverse rather than oblique, and (3) the annulations become relatively close together on the adoral portion of the living chamber rather than relatively far apart. However, when Foerste established this genus he stated that its "most distinctive feature" is a "more or less distinctly convex ventral outline," and that character is more strongly developed in the species under consideration than in any listed by Foerste.

Occurrence.—All four of the type specimens of this species came from the Bighorn dolomite on Medicine Mountain in the northern portion of the Bighorn Mountains. Congeneric forms are rather widespread in the United States and Canada, and they range in age from at least Lower Ordovician (Chazyan) to Middle Silurian (Cedarville and Racine).

Repository.—State University of Iowa, 2870 (holotype) and 2871 (paratypes).

LAMBEOCERAS spp.
Plate 76, figure 5

Our collections from the Bighorn Mountains contain four specimens that are probably referable to *Lambeoceras*. However, since none of them reveals the nature of its internal structures, at least part of them may possibly be referable to *Rasmussenoceras*, which differs from *Lambeoceras* chiefly in the character of the siphuncle.

Two of our specimens are very large, whereas the other two are comparatively small. The largest (pl. 76, fig. 5) attains a maximum width of some 185 mm. (estimated), and the other large specimen, though very incomplete, is of the same general magnitude. Both of these specimens are rather poorly preserved, and neither reveals the shape of the cross section. Their large size might be taken to indicate a relationship to *L. princeps* Troedsson of the

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EXPLANATION OF PLATE 76

All from talus boulders of Bighorn dolomite in the northern portion of the Bighorn Mountains. Figures *1*, *2*, *4*, and *5* from Medicine Mountain, *3* from Wallrock Creek just east of Hunt Mountain.

FIGS. *1–4*—*Exomegoceras wyomingense* Miller and Carrier, n. sp. *1*, *2*, Lateral and ventral views of the adapical half of the holotype, ×1. *3*, Lateral view of a specimen referred to this species with question, ×¾. *4*, Lateral view of the adoral half of the paratype, ×¾. (p. 541)

5—*Lambeoceras* sp. A large individual, ×½. (p. 537)

Cape Calhoun beds of northern Greenland, but in that species the sutures are somewhat recurved in the extreme lateral portions of the conch. It should be noted that the adoral portion of our figured specimen, which is probably septate throughout, appears to be slightly contracted laterally, and in the adoral portion of the phragmacone of large specimens of *L. princeps* the rate of expansion of the conch decreases greatly. Leith (1939, p. 1965) has recorded the occurrence of a very large representative of *Lambeoceras* in the Red River formation of Manitoba.

Both of our small specimens, which are also septate throughout, are very incomplete, but they show the characteristic lenticular cross section of the conch and are typical of *Lambeoceras* in all available particulars. In general physiognomy, the smallest resembles *L. cultratum* Miller, which was originally described from the Lander sandstone of the Wind River Mountains in west-central Wyoming. However, the specimen under consideration is so fragmentary that its specific affinities can not be determined with any reasonable degree of certainty, and its similarity to *L. cultratum* may well be more apparent than real.

Remarks.—Representatives of *Lambeoceras* are widespread in the United States and Canada and are fairly abundant in northern Greenland. As Foerste (1935, p. 51) has pointed out, they

> are not known at present below the level of the Stewartville and the Big Horn formations. They range to the top of the Richmond formation at Richmond, Indiana.

Occurrence.—All four of our specimens came from the Bighorn dolomite on Medicine Mountain in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2872 (figured specimen) and 2873 (three unfigured specimens).

Diestoceras spp.

Unfortunately, the four or five representatives of *Diestoceras* that we obtained are so incomplete or poorly preserved that they can not be identified specifically. One of them (State Univ. of Iowa, 2889) is an internal mold of the adoral portion of the living chamber, and it shows the recurved apertural margins. This specimen resembles one of the paratypes of *D. magister* Foerste from the Lander sandstone in the Wind River Mountains of western Wyoming, but it is only about two-thirds as large. Another of our specimens (State Univ. of Iowa, 2890) represents much of a phragmacone that attained a diameter of at least 75 mm. We have two fairly complete but rather poorly preserved specimens (State Univ. of Iowa, 2891) that superficially at least resemble *D. fremontense* Foerste of the Lander sandstone but are somewhat larger. Also, our collections contain a specimen (State Univ. of Iowa, 2892) that is somewhat similar to *D.? stensioei* (Troedsson) of the Lyckholm beds of Estonia.

Remarks.—The genus *Diestoceras* was originally based on specimens from the Richmond group of Ohio and Indiana, but it is now known to be rather widespread in the northern hemisphere and to range in age from Black River to Richmond. Representatives of it have been described from central and western United States; central, eastern, and arctic Canada; northern Greenland; southern Scotland; southern Norway; and Estonia.

Occurrence.—The specimens under consideration came from the Bighorn dolomite in the Bighorn Mountains; three of them came from Medicine Mountain, the other two (State Univ. of Iowa, 2890 and 2892) from Hunt Mountain.

Repository.—State University of Iowa, 2889–2892.

Neumatoceras dartoni
Miller and Carrier, n. sp.
Plate 77, figure 4

The specimen that serves as the holotype of this species is an internal mold of most of the living chamber and much of the phragmacone. Its length measures about 72 mm., of which about 35 mm. represent living chamber. The phragmacone is rather rapidly expanded orad, and the specimen attains its maximum dimensions near the junction of the phragmacone and the living chamber. There it is about 43 mm. high and about 32 mm. (estimated) wide. The cross section is subelliptical, but the conch appears to be somewhat more narrowly

rounded ventrally than dorsally. The living chamber is greatly contracted orad on at least the ventral side of the specimen. The ventral profile of the holotype is strongly convex throughout its entire length. Near the junction of the phragmacone and the living chamber, the dorsal portion of the conch is preserved for a length of some 22 mm.; at least this part of the dorsal profile is essentially straight.

In the adapical part of the holotype the sutures seem to be almost directly transverse and nearly straight, though they form very slight lateral lobes. In the adoral portion of the phragmacone, however, the sutures curve progressively orad on the ventral half of the conch and form distinct ventral saddles. The adoral camera of the holotype is considerably shorter than the preceding one, which indicates that the specimen represents a fully mature individual.

Remarks.—We are referring with question to this species four specimens from the same general horizon in the northern Bighorns that yielded the holotype. At least one of these is slightly larger than the holotype, and its surface, which is particularly well preserved for an internal mold, retains faint longitudinal grooves, which extend throughout the length of the phragmacone and the living chamber. Also, just orad of the adoral suture of this specimen there is a row of small rounded depressions much like those on the holotype of *Dowlingoceras? ornatum* Miller of the Lander sandstone in the Wind River Mountains of west-central Wyoming.

Our species resembles *N. nutans* Foerste, the holotype of which came from the same general horizon in the northern portion of the Bighorn Mountains. However, the conch of that species is distinctly smaller and also its phragmacone is more rapidly expanded orad.

Only a few representatives of *Neumatoceras* are known. All of these are from the Bighorn formation of Wyoming, the Fremont limestone of Colorado, the Whitehead formation of Quebec, and the Drummuck group of southern Scotland. However, it is possible that some of the specimens that have been described from the Red River formation of Manitoba, the Shamattawa limestone southwest of Hudson Bay, and strata of about the same age in the southeastern part of Baffin Island may be congeneric.

Occurrence.—Bighorn dolomite in the northern part of the Bighorn Mountains. The holotype and two of the specimens referred to the species with question were collected along Wallrock Creek just east of Hunt Mountain, whereas the two other questionable representatives of the species came from Medicine Mountain.

Repository.—State University of Iowa, 2893 (holotype), 2894 (Wallrock Creek specimens), and 2895 (Medicine Mountain specimens).

RICHARDSONOCERAS BIGHORNENSE
Miller and Carrier, n. sp.
Plate 77, figure 5

This species is based on three specimens, one of which (pl. 77, fig. 5) is much more nearly complete than the other two. This holotype is an internal mold of much of the phragmacone and much of the living chamber. Its length, measured along the midportion of the lateral zone, is about 183 mm., of which about 72 mm. represent living chamber. The holotype is curved exogastrically throughout its entire length, with the radius of curvature remaining almost constant but apparently decreasing orad very slightly. The cross section is subelliptical—the holotype appears to be slightly crushed along its dorsal zone, but the better of the paratypes, which seems to be free from distortion, is somewhat more narrowly rounded ventrally than dorsally. Near the junction of the phragmacone and the living chamber the holotype reaches its maximum dimensions, and there it is about 67 mm. high and some 49 mm. wide. The living chamber is distinctly contracted orad.

The shape of the sutures varies during ontogenetic development. On the adapical portion of the holotype the sutures are almost straight and directly transverse. Orad of there, however, they form low dorsal saddles, shallow lateral lobes, and higher ventral saddles. These inflections, particularly the ventral saddles, become increasingly prominent adorally. The siphuncle of the holotype is rather poorly preserved, but that of the better of the paratypes is located close to the ventral wall of the conch and is composed of segments that are abruptly ex-

panded within the camerae and are almost cylindrical in shape; that is, the septal necks are strongly recurved, and the connecting rings are essentially cylindrical but are abruptly contracted near their adapical ends. Where the conch is about 40 mm. high and about 30 mm. wide, the siphuncle is only 1 mm. or so high at its passage through a septum but is some 6 mm. high within the camerae. It appears to be slightly compressed laterally, and where it is about 6 mm. high its width measures only about 5 mm.

Remarks.—The conch of this species is of about the same size as that of *R. wyomingense* Foerste of the Lander sandstone of the Wind River Mountains in west-central Wyoming, but the sutures of that form do not develop progressively higher ventral saddles in the adoral portion of the phragmacone. *R. bighornense* seems to resemble much more closely *R. simplex* (Billings) of the Black River group of southern Ontario, which is the type species of the genus. This genotype, however, is a much smaller form than the species under consideration, and its living chamber is less strongly contracted orad.

Occurrence.—All three of the type specimens are from the Bighorn dolomite on Medicine Mountain in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2900 (holotype), 2901 (better paratype), and 2902 (poorer paratype).

WINNIPEGOCERAS LATICURVATUM
(Whiteaves)
Plate 78, figure 6

Cyrtoceras laticurvatum WHITEAVES, *1895*, Canadian Rec. Sci., vol. 6, pp. 395–396.
Cyrtoceras laticurvatum, WHITEAVES, *1897*, Canada Geol. Survey, Palaeozoic fossils, vol. 3, pt. 3, pp. 224–225, text fig. 14.
Winnipegoceras laticurvatum, FOERSTE, *1928*, Michigan Univ., Mus. Paleontology, Contr. vol. 3, pp. 56–58, pl. 9, figs. 1, 2.
Winnipegoceras laticurvatum, FOERSTE, *1935*, Denison Univ., Sci. Labs., Bull., vol. 30, pp. 38–39, pl. 4, fig. 2.
Winnipegoceras laticurvatum, ROY, *1941*, Field Mus. Nat. History, Geol. ser. Mem., vol. 2, pp. 143–144, text fig. 105.

An internal mold of a living chamber in the collections being studied is indistinguishable from corresponding portions of the holotype of *Winnipegoceras laticurvatum*. This specimen, which is slightly but distinctly concave dorsally and slightly convex ventrally, is about 90 mm. long and appears to be essentially complete adorally—it is bounded adapically by the impression of the adoral septum. The conch is compressed laterally and is elliptical (or nearly so) in cross section. At its adapical end the living chamber is about 37 mm. high and about 24 mm. wide. The adapical three-fourths of the living chamber are gradually contracted orad, but the adoral fourth is somewhat expanded. The minimum height and width of our specimen measure about 31.5 mm. and 18 mm., respectively, and corresponding measurements near the adoral end of the specimen are about 32.5 mm. and 20 mm., respectively.

The septa are strongly curved dorsoventrally but only slightly so laterally. The sutures form broad, deep, rounded lateral lobes and about equally prominent rather narrowly rounded dorsal and ventral saddles. An impression of the siphuncle in the adapical end of our specimen is about 3 mm. in diameter and lies some 5 or 6 mm. from the venter.

Remarks.—The slight variation in size shown by the several described specimens that have been referred to this species is presumably of no taxonomic importance. Although only the living chamber is represented by our specimen, there seems little reason to doubt that its affinities are with *Winnipegoceras laticurvatum*.

Occurrence.—This species was originally described from the Dog Head member of the Red River formation of southern Manitoba, and conspecific specimens have recently been described from the Lander sand-

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EXPLANATION OF PLATE 77

All from talus boulders of Bighorn dolomite in the northern portion of the Bighorn Mountains. Figures *1–3*, *5* from Medicine Mountain, *4* from Hunt Mountain.

FIGS. *1–3*—*Apsidoceras* sp. *1*, *2*, Two views of one specimen, ×½; *3*, another, ×¾. (p. 543)
4—*Neumatoceras dartoni* Miller and Carrier, n. sp. Lateral view of the holotype, ×¾. (p. 538)
5—*Richardsonoceras bighornense* Miller and Carrier, n. sp. Lateral view of the holotype, ×⅔. (p. 539)

Miller and Carrier, Ordovician Cephalopods

Miller and Carrier, Ordovician Cephalopods

stone in the Wind River Mountains of western Wyoming and from the approximately equivalent limestone of Frobisher Bay, Baffin Island. The specimen under consideration came from the Bighorn dolomite on Medicine Mountain in the northern portion of the Bighorn Mountains. A closely related form has been described from the Matapedia beds of southeastern Quebec.

Repository.—State University of Iowa, 2886.

Genus EXOMEGOCERAS Miller and Carrier, n. gen.

Genotype, *Exomegoceras wyomingense* Miller and Carrier, n. sp.

Several representatives of the genotype are available for study, but all of them are incomplete. However, they are all strongly curved exogastrically, are compressed laterally, and are oval in cross section, being subangular ventrally. The amount of longitudinal curvature seems to decrease adorally. At full maturity the living chamber appears to be somewhat contracted orad. The septa are strongly curved dorsoventrally but only slightly so laterally. The sutures form broad rounded lateral lobes, rounded dorsal saddles, and higher subangular ventral saddles. The siphuncle is rather small and is located fairly close to the venter. Its segments are not strongly expanded within the camerae.

Superficially the type species of this genus resembles the genotype of *Digenuoceras*, *D. latum* (Foerste) of the Red River formation of southern Manitoba and possibly the Bighorn dolomite of the northern Bighorns. However, Foerste states that in one of the specimens studied by him

> the lenticular cross section [of the conch] is clearly preserved, with both dorsal and ventral margins acutely angular.

Originally Foerste doubtfully referred *D. latum* to *Oxygenoceras*. That genus is based on *Trochoceras oxynotum* Barrande of the Middle Silurian of Bohemia, which is more strongly curved than *Exomegoceras wyomingense*, is not coiled in a plane, and has a moniliform siphuncle. In cross section, however, the conchs in the two genera are very similar.

At presemt, *Exomegoceras* is known to occur only in the Bighorn dolomite of the northern Bighorns.

EXOMEGOCERAS WYOMINGENSE Miller and Carrier, n. sp.

Plate 76, figures 1–4; text fig. 2

The holotype of this species (text fig. 2 and pl. 76, figs. 1, 2) is an internal mold of part of a phragmacone and part of a living chamber. Its length (measured along the midportion of the lateral zones) is about 107 mm. This specimen is rather strongly curved exogastrically, but the amount of its curvature seems to decrease adorally. The cross section is oval as the conch is compressed, is very broadly rounded laterally, more narrowly rounded dorsally, and subangular ventrally. Near the junction of the phragmacone and the living chamber, the height of the conch measures about 48 mm. and the corresponding width about 27 mm. The septa are only slightly curved laterally but are rather strongly curved dorsoventrally. The sutures form broadly rounded lateral lobes, more narrowly rounded dorsal saddles, and higher subangular ventral saddles.

The specimen represented by plate 76, figure 4, appears to be conspecific with the holotype, and we are regarding it as a paratype. However, it is considerably larger and the preserved portion of it attains a maximum height of conch of about 72.5 mm.—the corresponding width of conch can not be ascertained. The adapical half of this specimen is poorly preserved and is not figured. The septa and sutures do not differ materially from those of the holotype. A structure that probably represents the siphuncle is about 4 mm. in width and lies

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EXPLANATION OF PLATE 78

All from talus boulders of Bighorn dolomite in the northern portion of the Bighorn Mountains. Figures *1–3* from Wallrock Creek just east of Hunt Mountain, *4–6* from Medicine Mountain.

FIGS. *1–3*—*Charactocerina* spp. Two incomplete specimens, ×1. (p. 543)

4, 5—*Paractinoceras canadense* (Whiteaves). Ventral views of two specimens, ×1. (p. 544)

6—*Winnipegoceras laticurvatum* (Whiteaves). Lateral view of a living chamber, ×1. (p. 540)

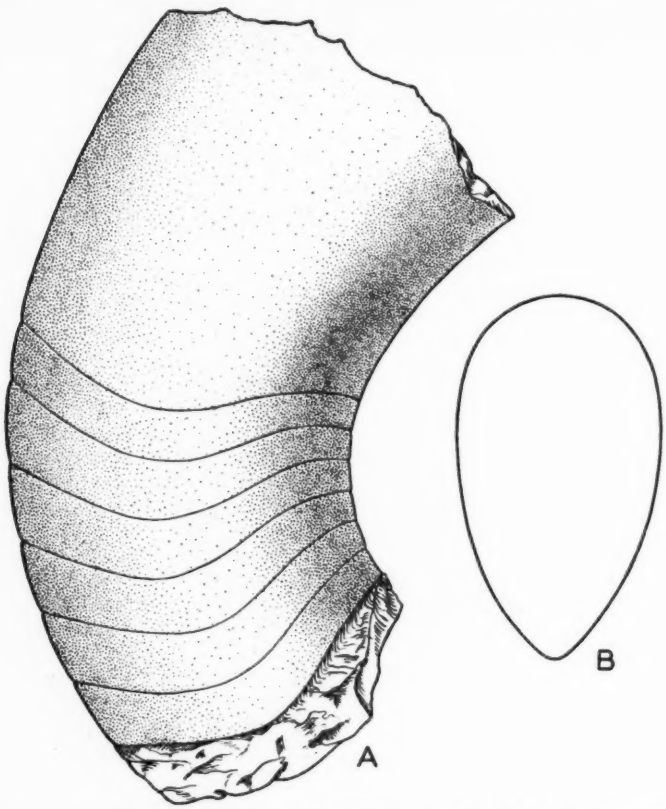

FIG. 2—*Exomegoceras wyomingense* Miller and Carrier, n. sp. Lateral view and outline cross section of the holotype showing the size and shape of the conch near the adoral end of the phragmacone, ×1.

fairly close to the venter. If, as we believe, this structure is an internal mold of the siphuncle, its segments are only slightly expanded within the camerae.

The cross section of the conch, the septa, and the sutures of the relatively large specimen represented by plate 76, figure 3, resemble those of the above-described individuals. This specimen is somewhat distorted, but its living chamber appears to be slightly but distinctly contracted orad. The two adoral camerae are shorter than the preceding ones, indicating that full maturity had been attained. The rather poorly preserved siphuncle of this specimen is compressed laterally, and it is about 4 mm. wide, about 5 mm. high, and some 2 mm. from the venter.

Remarks.—We are not certain in regard to the affinities of the specimen mentioned last and are referring it to this species with question. *Digenuoceras latum* (Foerste) seems to resemble this species, but its conch is angular rather than rounded dorsally.

Occurrence.—The type specimens (and three unfigured questionable representatives) of this species came from the Bighorn dolomite on Medicine Mountain in the northern Bighorns; the specimen of somewhat uncertain affinities, represented by plate 76, figure 3, came from the same formation along Wallrock Creek just east of Hunt Mountain, also in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2896 (holotype), 2897 (paratype), 2898 (figured specimen of questionable affinities), and 2899 (three fragmentary specimens doubtfully referred to this species.)

APSIDOCERAS sp.
Plate 77, figures 1–3

Two specimens were found in the Bighorn Mountains that belong in *Apsidoceras*. Unfortunately one of them (pl. 77, figs. 1, 2) represents only a small portion of the phragmacone, and the other (pl. 77, fig. 3) is somewhat distorted and preserves only part of the circumference of the conch. Therefore it is difficult to make detailed comparisons with described forms, and we are not even certain that both of our specimens are conspecific.

The conch of both specimens is almost flat ventrally, is abruptly rounded ventrolaterally, and is rounded dorsally (without any indication whatsoever of an impressed or contact zone). Near the adoral end of the specimen represented by plate 77, figures 1 and 2, the conch is about 62 mm. high and about 80 mm. wide.

The sutures of both of our specimens form broad, deep, rounded ventral lobes, high, narrowly rounded ventrolateral saddles, broad, shallow lateral lobes, and low, rounded dorsal saddles. The length of the camerae is elucidated by the accompanying illustrations.

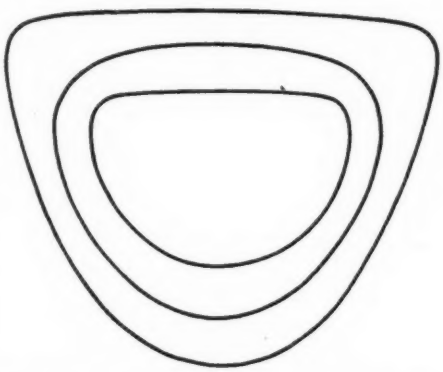

FIG. 3—Cross sections of mature conchs of *Apsidoceras magnificum* (Billings) [innermost], *A. elegans* Troedsson, and *A.* sp. [outermost], all ×¾. The first is after Foerste, the second after Troedsson, and the third is based on the specimen represented by pl. 77, figs. 1, 2.

Remarks.—The genus *Apsidoceras* is now known to occur in the Cape Calhoun beds of northwestern Greenland, the three Ordovician formations of Anticosti Island, the Whitehead beds of Gaspé Peninsula, the Shamattawa limestone southwest of Hudson Bay, and possibly the Stony Mountain formation of southern Manitoba. Our specimens seem to resemble most closely *A. magnificum* (Billings) of Anticosti Island and *A. elegans* Troedsson of Greenland. In cross section at least they seem to be more or less intermediate between these two forms; that is, the abrupt ventrolateral zones of their conchs are like those of *A. magnificum*, whereas their high, rather narrowly rounded dorsal zone is about like that of *A. elegans* (text fig. 3). It therefore seems likely that these Bighorn specimens represent an unnamed species, but neither of them would make a satisfactory holotype.

Occurrence.—Bighorn formation on Medicine Mountain in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2887 (pl. 77, figs. 1, 2) and 2888 (pl. 77, fig. 3).

CHARACTOCERINA spp.
Plate 78, figures 1–3

Charactocerina is represented in the collections under consideration by two incomplete specimens, which may be conspecific but which represent different portions of the conch. The adoral part of the smaller of these two specimens (pl. 78, figs. 1, 2) is distorted, but the adapical portion seems to retain the original shape of the conch. A little more than half of one volution of the conch is represented by this specimen. In cross section it is subelliptical as it is depressed dorsoventrally, broadly rounded ventrally, narrowly rounded laterally, and presumably somewhat impressed dorsally. At the adapical end of this specimen the conch is about 30.5 mm. wide and about 21 mm. high. The ventrolateral zones bear a row of narrowly rounded nodes, which are transversely elongate. The sutures are directly transverse to the long axis of the conch, but they form very slight lateral lobes and somewhat deeper ventral lobes.

The larger of our specimens (pl. 78, fig. 3) represents only about half of the circumference of the conch, but it appears to have been considerably wider than high. Its dorsal zone is distinctly impressed. Its ventro-

lateral zones bear prominent rounded nodes, which are considerably elongate transversely. The sutures of this specimen form broad rounded ventral and lateral lobes and more narrowly rounded ventrolateral saddles.

Remarks.—The smaller of our specimens seems to resemble somewhat the adapical portion of the conch of *Charactocerina costatula* (Miller) of the Lander sandstone of western Wyoming. However, its ventrolateral nodes are more prominent than are those of that species and suggest a relationship with our larger specimen, which has more prominent nodes than any previously described representative of this genus.

Occurrence.—Both of the above-described specimens came from the Bighorn dolomite on Wallrock Creek just east of Hunt Mountain in the northern Bighorn Mountains.

Repository.—State University of Iowa, 2884 (smaller specimen) and 2885 (larger specimen).

ACTINOCERAS spp.

Plate 75, figure 1; plate 79, figures 1–3

Five specimens in our collections seem to be referable to *Actinoceras*. There is considerable variation amongst these, and probably not all of them are conspecific. However, their incompleteness and rather poor preservation makes it impossible to determine their specific affinities.

The specimen represented by plate 75, figure 1, is about 163 mm. long, and it is septate throughout. It is considerably expanded orad, and the rate of divergence of its lateral zones indicates an apical angle of some 6°. Its conch is depressed dorsoventrally and is subelliptical in cross section but is more broadly rounded ventrally than dorsally. Near its adoral end it is about 40 mm. high and about 54 mm. wide. The sutures form broad, deep dorsal and ventral lobes and similar but narrower lateral saddles, all of which are of about equal prominence. The internal structures of this specimen are very poorly preserved, but at the adoral end of it there is an indication of a large siphuncle. Also, we are referring it to *Actinoceras* because of the similarity of its sutures and rate of adoral expansion to those of the specimen represented by plate 79, figures 2 and 3. This latter specimen shows certain structures in its siphuncle (pl. 79, fig. 3) which are reminiscent of those illustrated by the reconstructions of actinoceratoid siphuncles published by Saemann (1852, pl. 16, fig. 1h) and Teichert (1933, pl. 14, fig. 47; pl. 15, fig. 49). However, the preservation of our specimen is such that these structures are not very distinct.

Our largest specimen, represented by plate 79, figure 1, shows that the phragmacone of some of the Bighorn actinoceratoids attained a diameter of more than 110 mm., and a corresponding diameter of siphuncle of at least 70 mm. However, this specimen does not elucidate the cross section of the conch, and therefore we are not entirely certain in regard to its generic affinities.

Occurrence.—Bighorn dolomite on Medicine (three figured and one unfigured specimens) and Hunt (one unfigured specimen) mountains in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2879 (three figured specimens), 2880, and 2881.

PARACTINOCERAS CANADENSE (Whiteaves)

Plate 78, figures 4, 5; text figure 4

Sactoceras canadense WHITEAVES, *1892*, Royal Soc. Canada Trans., vol. 9, sec. 4, pp. 85–86, pl. 10, figs. 1–1c.

Orthoceras canadense, MILLER, *1892*, North American Geology and Palaeontology . . . , 1st App., p. 697. [Not *Orthoceras canadense* Billings, *1857*.]

Actinoceras (*Sactoceras?*) *canadense*, WHITEAVES, *1897*, Canada Geol. Survey Palaeozoic fossils, vol. 3, pt. 3, pp. 210–211.

Paractinoceras canadense, WHITEAVES, *1906*, Canada Geol. Survey Palaeozoic fossils, vol. 3, pt. 4, p. 344.

Paractinoceras canadense, FOERSTE, *1929*, Denison Univ., Sci. Labs., Bull., vol. 24, pp. 210–212, pl. 14, fig. 2, pl. 26, figs. 3a, 3b.

Paractinoceras canadense, MILLER, *1930*, Am. Jour. Sci., 5th ser., vol. 20, p. 200.

Paractinoceras canadense, MILLER, *1932*, Connecticut Acad. Arts and Sci. Trans., vol. 31, pp. 265–267, pl. 21, fig. 4.

Paractinoceras canadense, FOERSTE, *1935*, Denison Univ., Sci. Labs., Bull., vol. 30, p. 57, pl. 11, fig. 5.

Actinoceras (*Paractinoceras*) *canadense*, HYATT, *1900*, Zittel-Eastman Text-book of paleontology, vol. 1, p. 528.

Actinoceras (*Paractinoceras*) *canadense*, HYATT, *1913*, *idem.*, vol. 1, 2d ed., p. 609.

Actinoceras (*Paractinoceras*) *canadense*, BASSLER, *1915*, U. S. Nat. Mus. Bull. 92, vol. 1, p. 11.

We are referring to this species three specimens, two of which are represented by plate 78, figures 4 and 5, and the third by text figure 4. All three have been somewhat distorted during preservation, but they resemble the holotype rather closely. The conch is broadly elliptical in cross section, being somewhat depressed dorsoventrally. The phragmacone is expanded orad, but at full maturity the conch reaches a maximum diameter near the junction of the phragmacone and the living chamber and then contracts gradually toward the aperture.

The septa are moderately convex apicad and are directly transverse. The sutures of our specimens form broad ventral lobes, particularly in the adoral portion of the phragmacone, but these inflections may be due in part at least to distortion. The siphuncle is close to the ventral wall of the conch. The septal necks, which are about

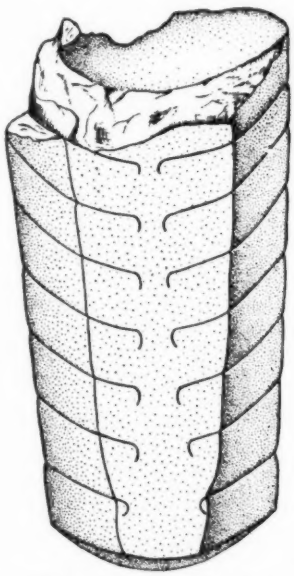

FIG. 4—*Paractinoceras canadense* (Whiteaves). Ventral view showing a longitudinal section through the siphuncle, ×1.

one-third as long as the camerae, are rather strongly recurved in the adapical portion of the phragmacone, but they become more nearly straight in the adoral portion. As shown by text figure 4, the size of the siphuncular segments decreases rather rapidly in the adoral part of the phragmacone of fully mature individuals.

Remarks.—The variation in size of the several representatives of this species that have been described is too slight to be of any taxonomic value. The unique adoral decrease in size of the siphuncle in the fully mature portion of the phragmacone is definitely known to occur in only the holotype and the specimen represented by text figure 4.

Occurrence.—The holotype of this species came from the lower or Dog Head member of the Red River formation in southern Manitoba. Miller has described a conspecific specimen from the Lander sandstone of the Wind River Mountains in western Wyoming, and Foerste has described another from the Bighorn dolomite on Medicine Mountain in the northern portion of the Bighorn Mountains. All three of our specimens came from the same horizon and locality as the one described by Foerste.

Repository.—State University of Iowa, 2883.

ARMENOCERAS spp.
Plate 79, figure 4

Representatives of the genus *Armenoceras* are fairly abundant in the Bighorn dolomite of the northern portion of the Bighorn Mountains, but for the most part only fragmentary internal molds of the siphuncle are to be obtained. Altogether our collections contain 24 specimens that belong in this genus. These show a great deal of variation in size and in the relative length of the siphuncular segments. The largest siphuncle that we have attains a maximum diameter of about 55 mm.

After giving these specimens careful consideration, we have concluded that it is probably not possible to identify species satisfactorily on the basis of the siphuncle alone, and therefore most of our specimens do not merit detailed description or illustration. The specimen represented by plate 79, figure 4, which is by far the best that we have, is about 275 mm. long. It attains a maximum diameter of about 85 mm. near its adoral end, where its siphuncle is about 42.5 mm. in diameter. The sutures form broad, shallow, rounded ventral lobes. Superficially, at least, this specimen re-

sembles *Armenoceras richardsoni* (Stokes) of the Red River formation of Manitoba and *A. clermontense* Foerste of the Maquoketa formation of Iowa; however, in both of those species the siphuncular segments are relatively long.

Occurrence.—We have representatives of *Armenoceras* from the Bighorn dolomite at the following localities in the northern portion of the Bighorn Mountains: Medicine Mountain (14 specimens), Hunt Mountain and along Wallrock Creek just east of Hunt Mountain (5 specimens), and Copemans Tomb (5 specimens, including the figured one).

Repository.—State University of Iowa, 2875 (figured specimen) and 2876–2878 (unfigured specimens).

SELKIRKOCERAS TYNDALLENSE Foerste
Plate 75, figures 2–4

Selkirkoceras tyndallense FOERSTE, *1929*, Denison Univ., Sci. Labs., Bull., vol. 24, p. 201, pl. 31, figs. 1A–1D.

The single specimen that we are referring to this species resembles the holotype very closely, though it retains the ventral wall of the conch and an internal mold of one camera of the phragmacone, whereas the holotype represents only siphuncle. The length of our specimen measures about 103.5 mm. The siphuncle is in contact with the ventral wall of the conch, and both it and the conch are almost flat ventrally and are broadly rounded dorsally. The preserved camera, which is about 38.5 mm. long, attains a maximum height and width of about 36.5 mm. and 58.5 mm., respectively.

Six, and part of a seventh, segments of the siphuncle are visible. These decrease progressively in size adorally. The adapical one of them, a considerable portion of which is covered by the preserved camera, is about 32 mm. high and about 50 mm. (estimated) wide. The fifth segment orad of this one (the last one that is preserved in its entirety) is about 21.5 mm. high and about 29 mm. wide.

Remarks.—As the above-described specimen is preserved in dolomite, the details of its internal structures are not ascertainable. However, all of its characters that can be determined agree very closely with those of the holotype of *S. tyndallense*.

Only two representatives of *Selkirkoceras* have been described previously, the holotypes of *S. cuneatum* Foerste (the genotype) and *S. tyndallense*. Both of these specimens came from the Selkirk member of the Red River formation of southern Manitoba.

Occurrence.—Bighorn dolomite in Wallrock Creek on the eastern side of Hunt Mountain in the northern portion of the Bighorn Mountains.

Repository.—State University of Iowa, 2874.

HURONIA OCCIDENTALIS Foerste
Text figure 5

Huronia occidentalis FOERSTE, *1928*, Denison Univ., Sci. Labs., Bull., vol. 23, pp. 97–98, pl. 10, figs. 1A–2.
Huronia occidentalis, FOERSTE, *1929*, *idem.*, vol. 24, pp. 141, 212.

A single specimen in our collections from the northern Bighorn Mountains seems to be referable to this species. It is an internal mold of six (and part of a seventh) segments of a siphuncle, and its length measures about 100 mm. One side of this specimen is essentially flat, indicating that it was in contact with the ventral wall of the conch over a considerable area. The apparent contact areas are elliptical or almost lenticular in shape. The specimen is considerably expanded orad; the adapical segment attains a maximum width of about 32 mm., the adoral of almost 38 mm. The maximum height of the adapical segment is about 26.5 mm.; due to incompleteness, the height of the adoral segment can not be ascertained. The shape and arrangement of the siphun-

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EXPLANATION OF PLATE 79

All from boulders of Bighorn dolomite in the northern portion of the Bighorn Mountains. Figures *1–3* from Medicine Mountain, *4* from Copemans Tomb.

FIGS. *1*—*Actinoceras?* sp. Natural longitudinal section of a large specimen, ×½. (p. 544)
2, 3—*Actinoceras* sp. Ventral view and longitudinal lateral section through the siphuncle, ×1. (p. 544)
4—*Armenoceras* sp. Natural longitudinal lateral section of a phragmacone, ×⅔. (p. 545)

Miller and Carrier, Ordovician Cephalopods

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cular segments are elucidated by text figure 5.

Remarks.—Foerste based this species on two specimens, one from the Bighorn formation of Wyoming and the other from the Red River formation of Manitoba. Our specimen seems to resemble the latter somewhat more closely than the former.

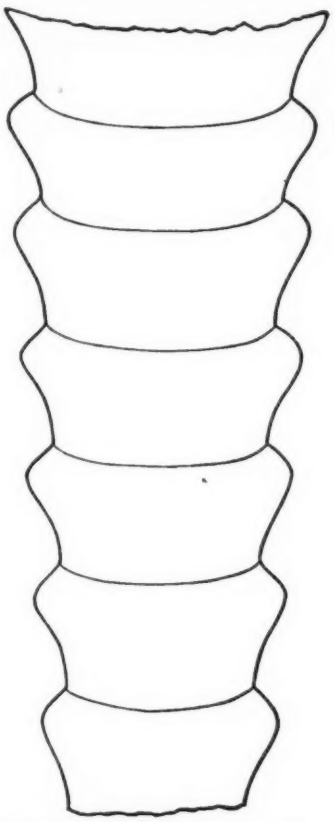

FIG. 5—*Huronia occidentalis* Foerste. Outline dorsal view of specimen from the Bighorn dolomite on Medicine Mountain in the northern Bighorn Mountains, ×1.

Only a few representatives of *Huronia* are known to occur outside of the Middle Silurian. These few came from the Cape Calhoun beds of northwestern Greenland, the Shamattawa limestone southwest of Hudson Bay and equivalent beds on Akpatok Island in Ungava Bay, the Red River formation of southern Manitoba, and the Bighorn formation of Wyoming—all of these beds are now generally believed to be correlative and to be referable to the Upper Ordovician.

Occurrence.—Bighorn formation on Medicine Mountain in the northern portion of the Bighorn Mountains. The syntypes came from the same formation on "Mocassin Mountain" in the Bighorn Mountains and from the Selkirk member of the Red River formation near the mouth of the Red River in southern Manitoba.

Repository.—State University of Iowa, 2882. The syntypes are in the U. S. National Museum.

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FAUNA AND STRATIGRAPHIC RELATIONS OF THE PROUT LIMESTONE AND PLUM BROOK SHALE OF NORTHERN OHIO

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ABSTRACT—The faunas of the two formations are illustrated on five plates. The Prout limestone is correlated with the Centerfield and the Plum Brook shale with the Levanna, both of Middle Devonian age.

INTRODUCTION

THE PROUT limestone and Plum Brook shale of northern Ohio, of Hamilton age, occupy the stratigraphic interval between the Delaware limestone and the Huron shale at the base of the Ohio shale sequence. These formations are of importance because they are the only post-Marcellus Hamilton beds to be found between the sections in western New York and those along the west flank of the Cincinnati axis with the exception of those in the Thedford and Arkona districts in Ontario. A knowledge of the fauna of these formations is necessary for accurate correlation of the Hamilton westward. The more common fossils occurring in the Plum Brook shale have been listed in previous reports, but very few Prout limestone fossils have been reported, and it has been difficult to place these formations in their proper position in the Hamilton sequence.

The scope of this paper is the identification of the megafauna of these beds and a discussion of their outcrop localities, together with notes on their correlation with the Hamilton of New York and the formations of Hamilton age on the west flank of the Cincinnati axis.

I am indebted to Oberlin College for a research grant enabling me to carry on the field work and other expenses incurred in the preparation of this paper; to Professor Fred Foreman of the Department of Geology and Geography of Oberlin College for his helpful interest and for supervision of the photographing of the fossils; and to Dr. G. A. Cooper of the U. S. National Museum for assistance in the identification of the brachiopods.

The Prout limestone and Plum Brook shale form the bedrock along an arcuate line running from northeast to southwest through Erie County from Slate Cut, just south of the shore of Lake Erie and four miles east of Sandusky, to Strong's Ridge, just northeast of the town of Bellevue (text fig. 1). Actual outcrops are few because of the covering of glacial drift. South of Strong's Ridge no outcrops have been found.

The Prout limestone is a hard,siliceous limestone varying from 3 to 9 feet in thickness. It forms a ridge that is topographically discernible at most points between Slate Cut and Strong's Ridge. The underlying Plum Brook shale is a soft gray shale containing thin bands of argillaceous limestone. Only the upper 20 feet of the formation is exposed, but well records in nearby localities give it a total thickness that varies from 40 to 60 feet. The glacial drift is thinner over the ridge produced by the Prout limestone, and this feature combined with the slight southward dip of the formations has enabled the northward flowing streams to cut through the limestone and into the upper part of the underlying shale.

PREVIOUS WORK

The first description of these formations was made by Newberry (1873, pp. 149–153). He mentioned 10 to 20 feet of marl and marly limestone of Hamilton age occurring at Prout Station, 8 miles south of Sandusky, immediately overlain by the Huron shale. He listed the following species as occurring in these beds: *Heliophyllum halli*, *Spirifer mucronatus*, *Stropheodonta demissa*, *Cyrtina hamiltonensis*, *Athyris spiriferoides*, and *Phacops rana*. Later Newberry (1874, pp. 189–190) discussed these beds again in a description of the geology of Erie County. He mentioned a second locality at Slate Cut and redescribed the section at the Prout Station locality as follows:

Newberry's Section at Prout Station

1. Huron shale; base.
2. Hamilton limestone, ferrugenous and cherty, with *Ancyrocrinus* and corals.. 10′
3. Hamilton marl, with *Phacops rana, Spirifer mucronatus, Cyrtina hamiltonensis, Athyris spiriferoides;* base not seen.. 20′

In the same volume, Newberry (1874, pp. 284–291) proposed the name Olentangy shale for those beds of gray calcareous shale outcropping along the banks of the Olentangy River in Delaware County, central Ohio. These beds have an average thickness of 30 feet and are almost entirely unfossiliferous but occupy the same stratigraphic interval between the Delaware limestone and the Huron shale as the formations in Erie County. He concluded that the Olentangy shale was not equivalent to the northern Ohio calcareous shales because of its unfossiliferous character and because it seemed to be interbedded with typical Huron shale in its upper layers.

Four years later Newberry (1878, pp. 11–13) reviewed the Hamilton formations of northern Ohio and mentioned the Prout

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EXPLANATION OF PLATE 80

FIGS. *1, 2*—*Ceratopora auloporoidea* (Davis). *1*, Small corallum, ×1, zone A, Plum brook section, O.C.G.M. (Oberlin College Geological Museum) 6007. *2*, Corallum with well preserved epitheca, ×1, zone A, Bloomingville section. O.C.G.M. 6008.

3—*Aulopora "serpens."* Specimen encrusting zoarium of *Eridotrypella obliqua*, ×1, zone A, Plum Brook section, O.C.G.M. 6009.

4—*Megistocrinus depressus* Hall. Base of calyx, ×1, zone B, Plum Brook section, O.C.G.M. 6010.

5, 6—*Eridotrypella obliqua* (Ulrich). *5*, Zoarium, ×1, with *Autodetus lindstromi* Clarke attached. *6*, Portion of surface, ×4. Zone A, Plum Brook section, O.C.G.M. 6011.

7—*Botryllopora socialis* Nicholson. Zoarium, ×1, zone A, Bloomingville section, O.C.G.M. 6012.

8–10—*Monotrypa?* sp. *8*, distal view of zoarium, ×1. *9*, Side view of another zoarium, ×1. *10*, Portion of surface of *8*, ×4. Zone A, Plum Brook section, O.C.G.M. 6013.

11, 12—*Eridotrypella appressa* (Ulrich). *11*, Zoarium, ×1. *12*, Portion of surface, ×4. Zone A, Bloomingville section, O.C.G.M. 6014.

13, 14—*Eridotrypella?* sp. *13*, Zoarium, ×1. *14*, Portion of surface, ×4. Zone A, Plum Brook section, O.C.G.M. 6015.

15—*Anomalotoechus tenera* (Bassler). Portion of encrusting zoarium, ×4, zone A, Plum Brook section, O.C.G.M. 6016.

16, 17—*Anomalotoechus "monticula."* *16*, Side view of zoarium, ×1. *17*, Portion of surface, ×4. Zone A, Plum Brook section, O.C.G.M. 6017.

18—*Hederella filiformis* (Billings). Encrusting zoarium, ×1, zone A, Bloomingville section, O.C.G.M. 6018.

19—*Hederella canadensis* (Nicholson). Encrusting zoarium, ×1, zone A, Plum Brook section, O.C.G.M. 6019.

20, 21—*Lioclema minutissimum* (Nicholson). *20*, Encrusting zoarium, ×1. *21*, Portion of surface, ×4. Zone A, Plum Brook section, O.C.G.M. 6020.

22—*Fenestrellina* sp. A. Portion of zoarium, ×1, zone F, Bloomingville section, O.C.G.M. 6021.

23, 24—*Cystodictya incisurata* Hall. *23*, Zoarium, ×1. *24*, Portion of surface, ×2. Zone D, Plum Brook section, O.C.G.M. 6022.

25, 26—*Streblotrypa hamiltonensis* (Nicholson). *25*, Zoarium, ×1. *26*, Portion of surface, ×3. Zone F, Plum Brook section, O.C.G.M. 6023.

27—*Acanthoclema* sp. Zoarium, ×3, zone F, Plum Brook section, O.C.G.M. 6024.

28—*Spirorbis omphalodes* Whiteaves. Specimen attached to zoarium of *Eridotrypalla obliqua*, ×1, zone A, Plum Brook section, O.C.G.M. 6025.

29—*Stropheodonta concava* Hall. Brachial valve, ×1, zone F, Plum Brook section, O.C.G.M. 6026.

30—*Stropheodonta demissa* (Conrad). Pedicle valve, ×1, zone B, Plum Brook section, O.C.G.M. 6027.

31—*Stropheodonta "plicata."* Pedicle valve, ×1, zone A, Bloomingville section, O.C.G.M. 6028.

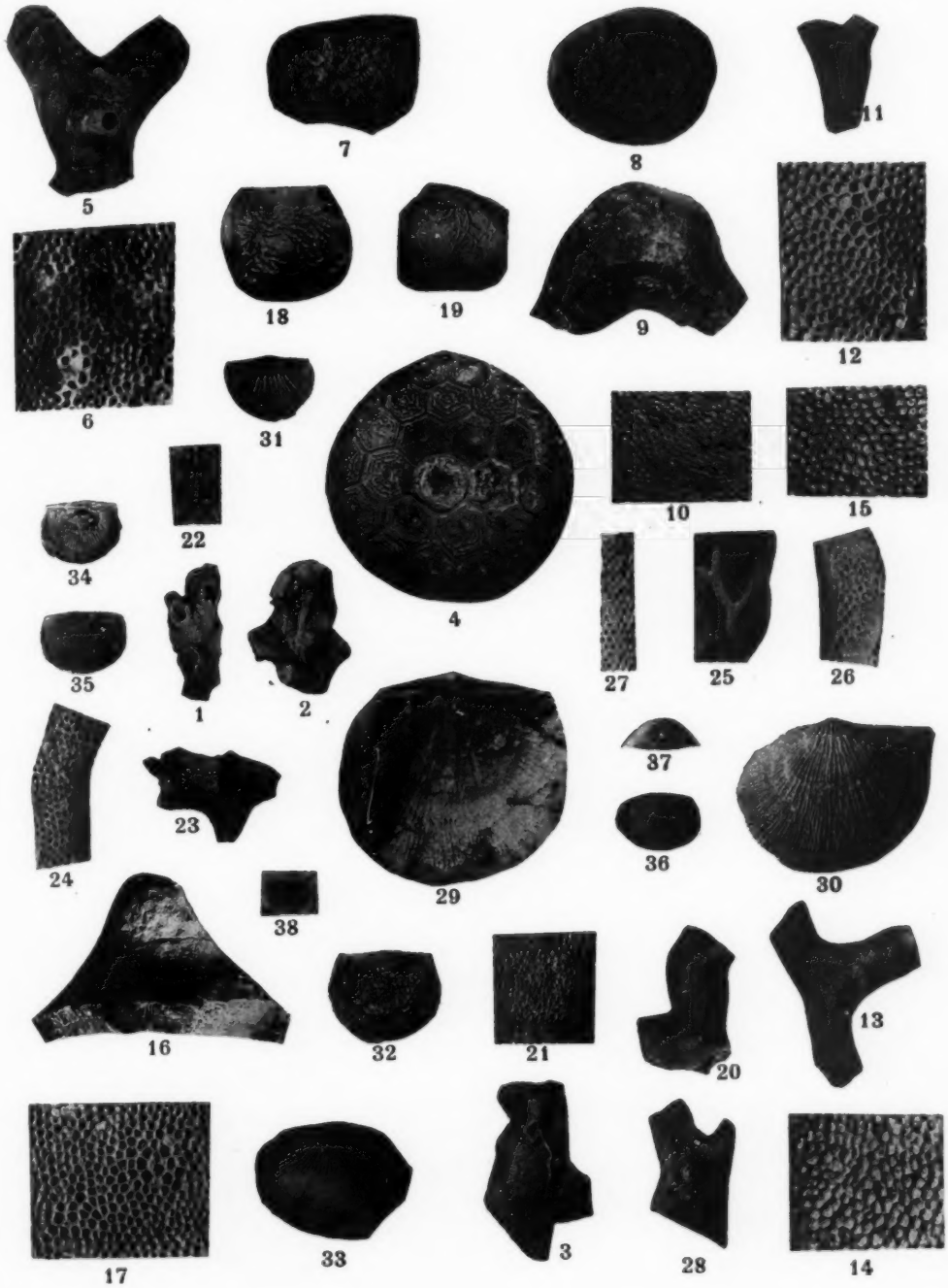
32—*Pholidostrophia nacrea* (Hall). Pedicle valve, ×1, zone A, Bloomingville section, O.C.G.M. 6029.

33—*Chonetes coronatus* (Conrad). Brachial valve, ×1, zone A, Bloomingville section, O.C.G.M. 6030.

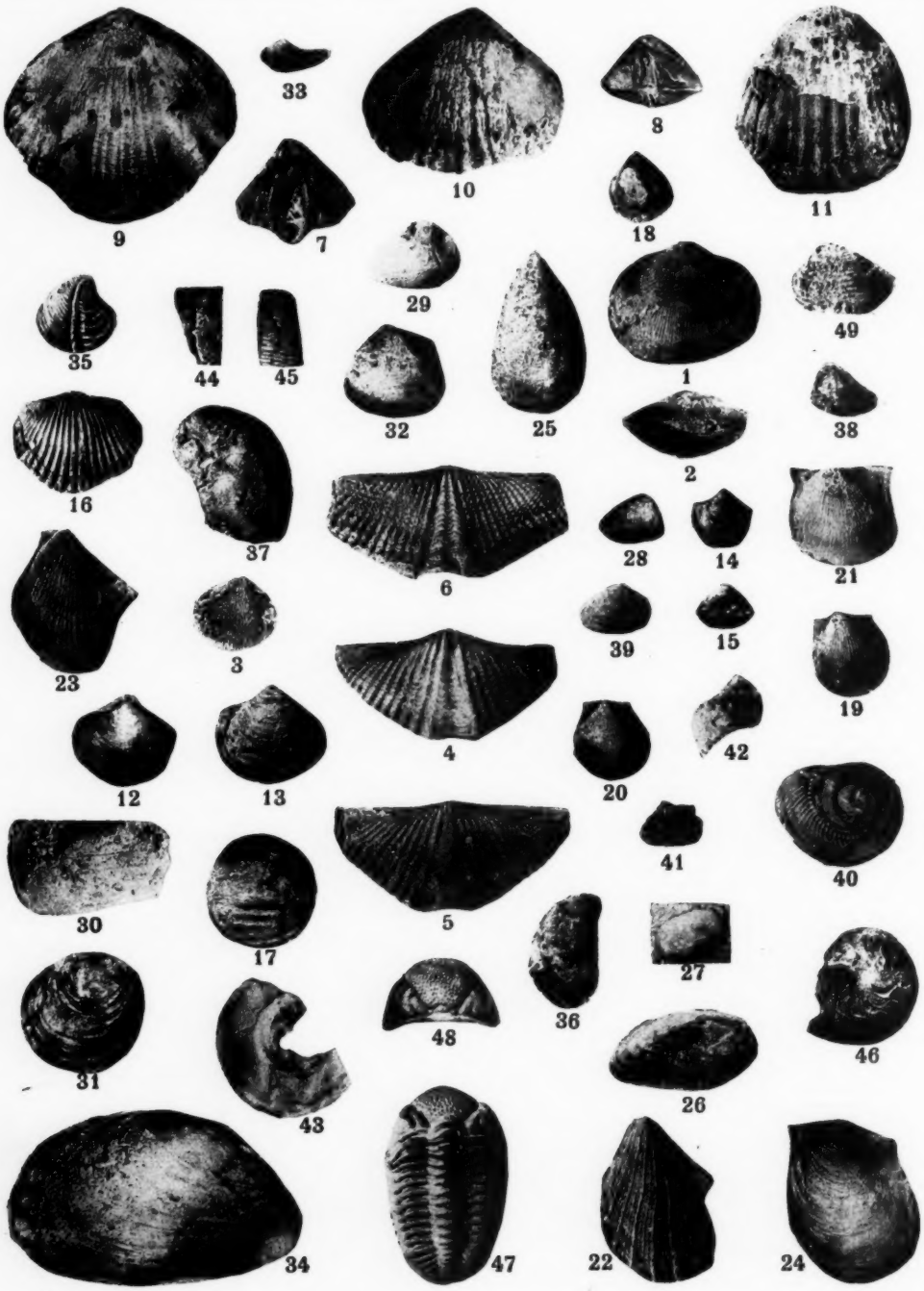
34, 35—*Chonetes scitulus* Hall. *34*, Brachial valve, ×1. *35*, Pedicle valve, ×1. Zone F, Plum Brook section, O.C.G.M. 6031.

36, 37—*Chonetes deflectus* Hall. *36*, Pedicle valve, ×1. *37*, Anterior view, ×1. Zone D, Plum Brook section, O.C.G.M. 6032.

38—*Chonetes setigerus* Hall. Pedicle valve, ×1, zone D, Plum Brook section, O.C.G.M. 6033.



Stumm, Fossils of the Plum Brook shale



Stumm, Fossils of the Plum Brook shale

EXPLANATION OF PLATE 81

FIGS. *1, 2—Schizophoria "striatula."* *1*, Brachial valve, ×1. *2*, Anterior view, ×1, zone A, Bloomingville section, O.C.G.M. 6034.

3—Schizophoria cyclas (Hall). Pedicle valve, ×1, zone A, Bloomingville section, O.C.G.M. 6035.

4, 5—"Spirifer" pennatus (Atwater). *4*, Pedicle valve, ×1. *5*, Brachial valve, ×1. Zone F, Bloomingville section. O.C.G.M. 6036.

6—"Spirifer" pennatus arkonensis Grabau. Brachial valve, ×1, zone F, Bloomingville section, O.C.G.M. 6037.

7, 8—Cyrtina hamiltonensis Hall. *7*, Pedicle valve, ×1. *8*, Posterior view, ×1. Zone A, Plum Brook section, O.C.G.M. 6038.

9, 10—Leiorhynchus kelloggi Hall. *9*, Pedicle valve, ×1. *10*, Brachial valve, ×1. Zone F, Bloomingville section, O.C.G.M. 6039.

11—Leiorhynchus laura (Billings). Pedicle valve, ×1, zone F, Plum Brook section, O.C.G.M. 6040.

12, 13—Athyris spiriferoides (Eaton). *12*, Brachial valve, ×1. *13*, Pedicle valve, ×1. Zone A, Plum Brook section, O.C.G.M. 6041.

14, 15—Ambocoelia umbonata (Conrad). *14*, Pedicle valve, ×1. *15*, Anterior view. Zone B, Plum Brook section, O.C.G.M. 6042.

16—Tropidoleptus carinatus (Conrad). Pedicle valve, ×1, zone A, Plum Brook section, O.C.G.M. 6043.

17—Petrocrania hamiltonae (Hall). Upper valve, ×2, zone F, Plum Brook section, O.C.G.M. 6044.

18—Cryptonella planirostris (Hall). Brachial valve, ×1, zone A, Plum Brook section, O.C.G.M. 6045.

19—Aviculopecten fasciculatus Hall. Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6046.

20—Aviculopecten princeps? (Conrad). Small left valve, ×1, zone F, Bloomingville section, O.C.G.M. 6047.

21—Pterinopecten vertumnus Hall. Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6048.

22—Pterinea flabellum (Conrad). Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6049.

23—Actinopteria boydi (Conrad). Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6050.

24—Leiopteria rafinesqui Hall. Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6051.

25—Plethomytilus oviformis (Conrad). Left valve, ×1, zone A ,Bloomingville section, O.C.G.M. 6052.

26—Nyassa arguta Hall. Right valve, ×1, zone F, Plum Brook section, O.C.G.M. 6053.

27—Nyassa recta Hall. Weathered right valve, ×1, zone B, Plum Brook section, O.C.G.M. 6054.

28—Nucula corbuliformis Hall. Right valve, ×1, zone B, Plum Brook section, O.C.G.M. 6055.

29—Nuculites triqueter Conrad. Right valve, ×1, zone B, Plum Brook section, O.C.G.M. 6056.

30—Sphenotus cuneatus (Conrad). Portion of right valve, ×1, zone F, Plum Brook section, O.C.G.M. 6057.

31—Paracyclas lirata (Conrad). Right valve, ×1, zone F, Plum Brook section, O.C.G.M. 6058.

32—Schizodus appressus (Conrad). Left valve, ×1, zone F, Plum Brook section, O.C.G.M. 6059.

33—Leda rostellata (Conrad). Left valve, ×1, zone A, Plum Brook section, O.C.G.M. 6060.

34—Modiomorpha subalata (Conrad). Right valve, ×1, zone F, Plum Brook section, O.C.G.M. 6061.

35—Grammysia bisulcata (Conrad). Right valve, ×1, zone B, Plum Brook section, O.C.G.M. 6062.

36—Platyceras arkonense Shimer and Grabau. Posterior view, ×1, zone F, Plum Brook section, O.C.G.M. 6063.

37—Platyceras erectum Hall. Side view, ×1, zone F, Plum Brook section, O.C.G.M. 6064.

38—Bellerophon lyra Hall. Posterior view, ×1, zone F, Plum Brook section, O.C.G.M. 6065.

39—Tellinopsis subemarginata (Conrad). Right valve, ×1, zone F, Plum Brook section, O.C.G.M. 6066.

40—Bembexia sulcomarginata (Conrad). Distal view, ×1, zone F, Plum Brook section, O.C.G.M. 6067.

41—"Pleurotomaria" capillaria Conrad. Side view of incomplete specimen, ×1, zone F, Plum Brook section, O.C.G.M. 6068.

42—"Pleurotomaria" rotalia Hall. Side view, ×1, zone F, Plum Brook section, O.C.G.M. 6069.

43—"Pleurotomaria" planodorsalis? Hall. Distal view of incomplete specimen, ×1, zone B, Plum Brook section, O.C.G.M. 6070.

44, 45—Bactrites arkonensis Whiteaves. *44*, View of small specimen. *45*, Side view of larger, laterally compressed specimen. Zone A, Plum Brook section, O.C.G.M. 6071.

46—Tornoceras uniangulare (Conrad). Side view, ×1, zone A, Plum Brook section, O.C.G.M. 6072.

47, 48—Phacops rana (Green). *47*, Complete individual. *48*, Cephalon of another specimen. Zone D, Bloomingville section, O.C.G.M. 6073.

49—Cypricardinia indenta (Conrad). Left valve, ×1, zone F, Plum Brook section, 6073a.

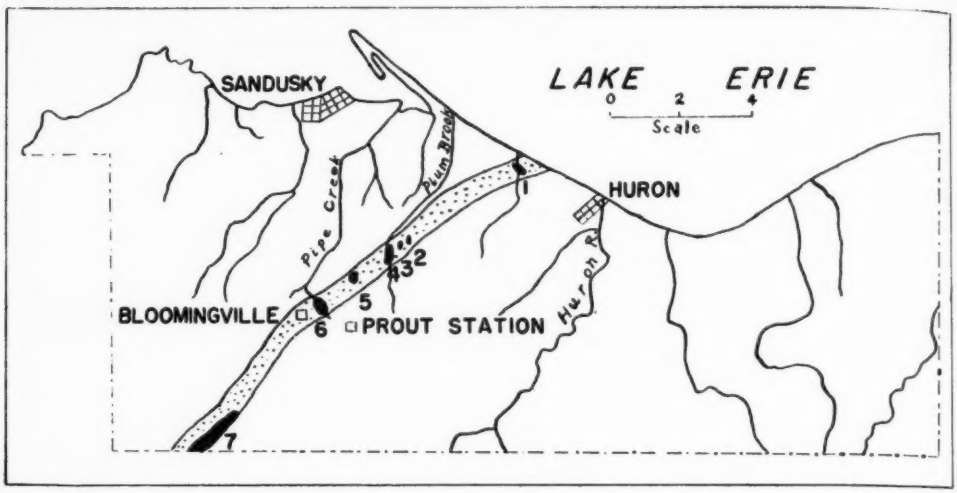


FIG. 1—Outcrops of the Prout limestone and the Plum Brook shale in Erie County, Ohio. 1, Slate Cut, along New York Central Railroad 4 miles west of Huron. 2, Small anticline on south side of Fox Road 1 mile east of bridge crossing Plum Brook. 3, Small quarry on north side of Fox Road half a mile east of bridge crossing Plum Brook. 4, Plum Brook about 2 miles northeast of Prout Station. 5, Deep Cut, along Baltimore & Ohio Railroad about 1 mile north of Prout Station. 6, Along tributary of Pipe Creek a quarter of a mile east of Bloomingville. 7, Strong's Ridge, 3 to 5 miles northeast of Bellevue.

station section. In addition to the species quoted previously he listed *Tropidoleptus carinatus* and *Nyassa arguta* as occurring in these beds.

In 1893, Orton (p. 20) discussed the "15 to 20 feet of highly fossiliferous blue shale" occurring at Prout Station and considered it to be the equivalent of the Olentangy shale of Delaware County "because they occupy the same stratigraphic position between the top of the Corniferous limestone and the base of the Ohio shale." At this time no distinction had been made between the Columbus and Delaware limestones, and the term "Corniferous" included all the beds lying between the top of the Monroe group and the base of the Olentangy shale.

The first mention of the name Prout limestone was made by Prosser (1903, p. 47) in a short report on the field activities of the biological club. The following sentence is the only mention made of the formation: "Exposures of the Prout limestone at the base of the Huron were found." No discussion of the formation or mention of a type locality was made.

Stauffer (1907, pp. 592–596) discussed the Hamilton formations of Ohio and on p. 592 made the statement:

> Dr. Newberry agreed that the Olentangy shale may be Hamilton and this was evidently supported by the fauna of the Prout limestone, a thin, fossiliferous layer occurring immediately below the Huron shale.

The first detailed study of these formations was made by Stauffer (1909, pp. 115–122). He redescribed the sections at Prout Station and Slate Cut and described three new sections at the following localities: Plum Brook, 1½ miles northeast of Prout Station; tributary of Pipe Creek, ¼ mile east of Bloomingville; and Strong's Ridge, 3 miles east of Bellevue. The most complete exposures were those at Plum Brook and Bloomingville. He divided the formations into eight zones at the former locality and four zones at the latter. In this, as well as in his subsequent papers, he considered these beds to be the equivalent of the Olentangy shale of central Ohio and considered the Prout limestone to be the top member of the "Olentangy" formation in northern Ohio. Stauffer quoted fossil lists from these localities, most of the species of which were from the underlying shale.

In a discussion of the Huron shale in

northern Ohio Prosser (1913, p. 326) redescribed the Slate Cut section and noted the occurrence of 2 feet, 2 inches of dark gray, hard limestone weathering brown and containing many cup corals, crinoid fragments, and other fossils at the base of the Huron shale. In a footnote on the same page he revealed that he proposed the name Prout limestone in 1903 and mentioned that he concurred with Stauffer in considering it a lentil or member of the "Olentangy" formation.

Later, Stauffer (1916, pp. 467–487) restudied the Plum Brook and Bloomingville localities. In the first he recognized 11 zones, of which the Prout limestone formed the topmost. The other 10 zones were based on the alternation of shale and thin argillaceous limestone bands in the Plum Brook formation. In addition to the fauna listed in 1909, new species were reported from most of the zones. No rezoning was made in the Bloomingville section, but more fossils were reported from both the Prout and the upper layers of the Plum Brook. Stauffer mentioned the alternation of shale and argillaceous limestone bands in the Plum Brook formation at this locality, but as they were poorly exposed, he did not correlate them with those in the Plum Brook section.

In a discussion on the relationship between the Prout limestone and Plum Brook shale in northern Ohio and the typical Olentangy shale of central Ohio, Grabau (1917, pp. 337–343) briefly discussed the Deep Cut, Slate Cut, and Plum Brook sections. He proposed the name Prout series[1] for the Prout limestone and "Olentangy" shale of northern Ohio and the name Plum Creek shale for the interbedded shales and argillaceous limestone bands exposed beneath the Prout in the Plum Brook section. Grabau proposed these names on the basis that these beds were not the equivalent of the Olentangy shale of central Ohio, a view directly opposite to that held by Stauffer. The name Plum Creek is preoccupied, and G. A. Cooper has suggested the term Plum Brook shale for these beds. This name is suitable because Plum Brook and not Plum Creek is the official designation for the stream at the type locality.

[1] This name was first proposed in 1915 in an abstract in *Geol. Soc. America Bull.*, vol. 26, p. 112.

In 1938, Stewart, in a description of the Middle Devonian corals of Ohio described all previously reported corals from the Prout and Plum Brook formations and described several new species from these localities.

Stauffer (1938, pp. 411–443) has described many conodonts from the shale in these sections.

EXPOSED SECTIONS IN NORTHERN OHIO

Deep Cut section.—This section lies in a cut of the Baltimore & Ohio Railroad, 1 mile north of Prout Station, Erie County. It has been designated as the type locality for the Prout limestone, but the choice is an unfortunate one as only the upper 2 feet of the formation are now exposed. In Newberry's original description of this locality in 1874 the entire formation was exposed with a total thickness of 10 feet, and also the upper 20 feet of the underlying shale. Stauffer's redescription of the section in 1909 mentions that only the upper 5 feet of the Prout is visible and that

> whatever may have been uncovered farther down the ditch to the north is now completely concealed.

At present only the very top of the Prout can be seen, and the contact with the overlying Huron shale is largely obscured by slope wash. The present section at Deep Cut appears as follows:

Section at Deep Cut

	Ft.	in.
Huron shale:		
Black shale, mainly covered.....	2	
Prout limestone:		
Black chert, weathering gray.....	0	6
Siliceous grayish-brown limestone.....	1	6

Fossils are rare in this part of the formation at this locality, but a few specimens of *Heliophyllum halli*, *Ceratopora intermedia*, and *Atrypa "reticularis"* were found.

Plum Brook section.—This section, the type locality for the Plum Brook shale, is exposed along the banks of Plum Brook about 2 miles northeast of Prout Station. Since Stauffer's (1916, pp. 476–478) excellent description of this section was written, the shale has become more and more covered until now only the two lower calcareous bands (Stauffer's zones 7 and 5) can be seen in place, and the upper band (Stauffer's zone 9) can be determined by

float boulders. The intervening shale beds are almost completely covered. In a few places weathered parts can be reached by digging in the bank. The basal part of the shale (Stauffer's zones 4–1) is so badly covered that these zones can no longer be differentiated. Fossils can be obtained from the shale beds only by washing the weathered material near the surface. The Plum Brook section is as follows:

Section at Plum Brook

	Ft.	in.
Huron shale:		
Black, carbonaceous shale	3±	
Prout limestone:		
Zone J. Siliceous grey limestone weathering brown	3±	
Characteristic species: *Heterophrentis prolifica, Heliophyllum reflexum, Ceratopora intermedia, Eridophyllum subcaespitosum, Favosites hamiltonae.*		
Zone I. Gray to white crinoidal limestone	3±	
Characteristic species: *Heliophyllum halli, Chonetes mucronatus, Camarotoechia sappho, "Spirifer" angustus, "S" venustus.*		
Zone H. Gray to brown siliceous limestone	2±	
Characteristic species: *Heterophrentis prolifica, Heliophyllum halli, Atrypa "reticularis"*		
Plum Brook shale:		
Zone G. Gray shale, entirely covered.	3±	
Zone F. Soft gray argillaceous limestone	0	10
Characteristic species: *Stropheodonta concava, S. dimissa, "Spirifer" pennatus arkonensis, Leiorhynchus kelloggi, Actinopteria boydi, Modiomorpha subalata, Phacops rana.*		
Zone E. Soft gray shale, completely covered. Some fossils loose on slopes.	3±	
Characteristic species: *Chonetes scitulus, C. setigerus, Leiorhynchus kelloggi.*		
Zone D. Hard gray argillaceous limestone	0	6
Characteristic species: *Cystodictya incisurata?, Chonetes setigerus, Phacops rana.*		
Zone C. Soft gray shale, completely covered. Weathered portions seen by digging into bank	6±	
Zone B. Hard gray argillaceous limestone	0	8
Characteristic species: *Ambocoelia umbonata, Chonetes setigerus, Nuculites triqueter, Nyassa recta, Phacops rana.*		
Zone A. Soft gray shale, completely covered. Fossils weathered loose along banks	15±	
Characteristic species: *Ceratopora auloporoidea, Anomalotoechus "monticula," Cyrtina hamiltonensis, Tropidoleptus carinatus, Leda rostellata, Bactrites arkonensis, Tornoceras uniangulare.*		

Bloomingville section.—As the section at Bloomingville shows the most nearly complete exposures of both the Prout limestone and the Plum Brook shale at the present time, it is best to consider it as the standard section for these formations. The outcrops lie along the banks of a tributary of Pipe Creek, ¼ mile east of the village of Bloomingville, Erie County. The entire Prout limestone is exposed in small overlapping sections, and the upper 25 feet of the Plum Brook shale is intermittently exposed farther down stream. Here, as in the Plum Brook section, I have divided the Prout into three, and the exposed part of the Plum Brook into seven zones, based on both faunal and lithologic differences. The three calcareous bands in the Plum Brook shale can be correlated directly with those exposed at Plum Brook, and the distances between them are about the same at both localities. The section is as follows:

Section near Bloomingville

	Ft.	in.
Prout limestone:		
Zone J. Hard, siliceous gray to brown limestone, containing much chert and pyrite and occasional softer, more calcareous bands	3±	
Characteristic species: *Heterophrentis prolifica, Heliophyllum confluens, Eridophyllum subcaespitosum, Ceratopora intermedia, Favosites hamiltonae.*		
Zone I. Hard to soft gray crinoidal limestone, becoming shaly at the base	3±	
Characteristic species: *Ceratopora nobilis, Eunella attenuata, Camarophoria kernahani, "Spirifer" angustus, "S." sculptilis, "S." venustus, Pentagonia bicostata.*		
Zone H. Hard, siliceous gray to brown limestone	3±	
Characteristic species: *Heterophrentis prolifica, Heliophyllum halli, H. reflexum, Atrypa "reticularis."*		
Plum Brook shale:		
Zone G. Soft gray shale, mainly covered and apparently unfossiliferous.	2	4
Zone F. Soft argillaceous gray limestone, very fossiliferous	1	0
Characteristic species: *Stropheo-*		

FOSSILS IN THE PROUT LIMESTONE AND PLUM BROOK SHALE

s, Reported by Stauffer, 1916; *t*, by Stewart, 1939; *u*, by Newberry, 1874.	J	I	H	G	F	E	D	C	B	A
Stromatoporoids										
Coenostroma pustulifera Winchell	×									
Corals										
Acrophyllum n. sp.	×									
Alveolites goldfussi Billings		×								
A. monroei Cleland										s
Amplexus hamiltonae Hall	×									
Aulacophyllum hemicrassatum Sloss	×									
Aulopora "serpens"										×
Blothrophyllum cinctutum Davis	×									
B. conatum (Hall)	×									
Ceratopora auloporoidea (Davis)										×
C. intermedia (Nicholson)	×									
C. nobilis (Billings)		×								
Cladopora fisheri (Billings)	×	×								
C. frondosa (Billings)	×	×								
C. roemeri (Billings)	×	×								
"Cystiphyllum" vesiculosum	×	×	×							
"C" n. sp.	×									
Emmonsia arbuscula (Hall)	×									
Eridophyllum archiaci (Billings)		×								
E. seriale Edwards and Haime		×								
E. subcaespitosum (Nicholson)	×									
Favosites alpenensis Winchell	×	×	×							
F. argus Hall	×		×							
F. hamiltonae Hall	×	×	×							
F. nitella Winchell	×	×								
F. placenta Rominger	×	×	×							
F. radiciformis Rominger	t									
F. turbinatus Billings	×	×	×							
Heliophyllum arachne Hall	×	×	×							
H. confluens Hall	×									
H. degener Hall	×									
H. halli Edwards and Haime	×	×	×							
H. reflexum Hall	×	×	×							
H. scyphus Rominger		×								
H. sp.	×									
Heterophrentis prolifica Billings	×	×	×							s
H. simplex (Hall)	×	×	×							
Michelinia dividua (Hall)	×									
Romingeria cornuta (Billings)										s
Stereolasma rectum (Hall)	×	×	×							
Striatopora sp.	×									
Syringopora perelegans Billings										s
Trachypora elegantula (Billings)		×								
T. limbata (Eaton)	×									
Tortophyllum cysticum (Winchell)	×									
Crinoids										
Ancyrocrinus sp.	u									
Arthracantha sp.	×	×								
Dolatocrinus sp.	×									
Megistocrinus depressus Hall									×	
M. ontario Hall	×	×								
M. rugosus Lyon and Cassidy	×									
Bryozoa										
Acanthoclema sp.					×					
Anomalotoechus aff. *monticula*					?					×
A. tenera (Bassler)										×
Ascodictyon stellatum Nicholson and Etheridge										s
Botryllopora socialis Nicholson										×

FOSSILS IN THE PROUT LIMESTONE AND PLUM BROOK SHALE—*Continued*

s, Reported by Stauffer, 1916; *t*, by Stewart, 1939; *u*, by Newberry, 1874.	J	I	H	G	F	E	D	C	B	A
Cystodictya incisurata Hall					×	×	×		×	
Eridotrypella appressa (Ulrich)					×					×
E. obliqua (Ulrich)										×
E? sp.										×
Fenestrellina sp. A					×					
F. sp. B	×									
F. sp. C	×	×								
"Fistulipora" corrugata? Ulrich					×					
"F." spinulifera Rominger										×
Hederella canadensis (Nicholson)					×					×
H. cirrhosa Hall					×					
H. filiformis (Billings)					×		×		×	×
Heteronema monroei Cleland										s
Lioclema minutissimum (Nicholson)										×
Monotrypa? sp.										×
Reteporina sp. A	×	×	×							
R. sp. B	×	×								
Streblotrypa hamiltonensis (Nicholson)					×					
Worms										
Autodetus lindstromi Clarke										×
Spirorbis angulatus Hall					s					
S. omphalodes Whiteaves					×					
Brachiopods										×
Athyris spiriferoides (Eaton)	×	×	×							×
A. vittata Hall		×								
Atrypa "reticularis"	×	×	×							s
A. spinosa Hall		×								
Ambocoelia umbonata (Conrad)									×	
Camarophoria kernahani (Whiteaves)		×								
Camarospira sp. A	×	×								
C. sp. B		×								
C. sp. C		×								
Camarotoechia congregata (Conrad)		×								
C. depressa Kindle		×								
C. sappho (Hall)		×								
C. thedfordensis Whiteaves		×								
Chonetes coronatus (Conrad)		×								×
C. deflectus Hall					×	s	×	s	×	×
C. mucronatus Hall		×								
C. scitulus Hall					×		×		×	×
C. setigerus Hall					×	×	×	×	×	×
Cranaena romingeri (Hall)		×								
C. sp.		×								
Crania crenistriata Hall					×	s				
Craniella hamiltonae Hall					×		×		×	×
Cyclorhina nobilis Hall		×								
Cyrtina hamiltonensis Hall		×			×		×		×	×
Cryptonella planirostris (Hall)										×
Douvillina inaequistriata Hall		×								
Eunella attenuata Whiteaves		×								
Leiorhynchus kelloggi Hall					×	×	×	×	×	×
L. laura (Billings)					s		s			×
Leptostrophia perplana (Conrad)		×								
Lingula ligea Hall	×									
L. thedfordensis Whiteaves	×									
Parazyga hirsuta Hall		×								
Pentagonia bicostata Hall	×	×								
Pentamerella pavilionensis Hall		×								
Pholidostrophia nacrea (Hall)										×
Productella navicella Hall		×								

FOSSILS IN THE PROUT LIMESTONE AND PLUM BROOK SHALE—*Continued*

s, Reported by Stauffer, 1916; *t*, by Stewart, 1939; *u*, by Newberry, 1874.	J	I	H	G	F	E	D	C	B	A
P. spinulicosta Hallé		×								
Reticularia fimbriata (Conrad)	×	×	×							
Rhipidomella penelope Hall		×								
R. vanuxemi Hall	×	×	×							
Schizophoria cyclas (Hall)										×
S. "striatula"										×
Schuchertella arctostriata (Hall)		×								
S. perversa (Hall)		×								
"Spirifer" angustus Hall	×	×								
"S." audaculus (Conrad)		×								
"S." consobrinus d'Orbigny		×								
"S." pennatus (Atwater)	×	×			×	×	×	×	×	×
"S." pennatus arkonensis Shimer & Grabau					×		×		×	×
"S." sculptilis Hall	×	×								
"S." venustus Hall	×	×								
Stropheodonta concava Hall		×			×					
S. demissa (Conrad)	×	×	×		×		×		×	×
S. "plicata"										×
Tropidoleptus carinatus (Conrad)										×
Pelecypods										
Actinopteria boydi (Conrad)					×		×		×	×
Aviculopecten fasciculatus Hall					×				×	
A. princeps? (Conrad)					×				×	
Cypricardella bellistriata (Conrad)					s					
Cypricardinia indenta (Conrad)					×				×	
Glyptocardia speciosa Hall									s	
Gosselettia triquetra (Conrad)					s					
Grammysia arcuata (Conrad)									s	
G. bellatula Hall									s	
G. bisulcata (Conrad)									×	
G. constricta Hall									s	
Leiopteria rafinesqui Hall					×					
Leda rostellata (Conrad)										×
Modiomorpha concentrica (Conrad)		×								
M. subalata (Conrad)					×				×	×
Nucula corbuliformis Hall					×		×		×	
Nuculites oblongatus (Conrad)										s
N. triqueter (Conrad)									×	
Nyassa arguta Hall					×					
N. recta Hall									×	
Paracyclas elliptica Hall	×	×								
P. lirata (Conrad)					×					
Plethomytilus oviforme (Conrad)					×					×
Pterinea flabellum (Conrad)		×			×					
Pterinopecten vertumnus Hall					×					
Pholadella radiata (Conrad)									s	
Schizodus appressus (Conrad)					×				×	×
Sphenotus cuneatus (Conrad)					×				×	×
Tellinopsis subemarginata (Conrad)					×					
Gastropods										
Bellerophon lyra Hall					×					
B. sp.		×								
Bembexia sulcomarginata (Conrad)					×					
Cyrtonella mitella Hall					s					
Diaphorostoma lineatum (Conrad)		×								
Loxonema sp. A		×								
L. sp. B	×									
Platyceras arkonense Shimer & Grabau					×					
P. carinatum Hall		×								
P. erectum Hall		×			×		×			

FOSSILS IN THE PROUT LIMESTONE AND PLUM BROOK SHALE—*Continued*

s, Reported by Stauffer, 1916; *t*, by Stewart, 1939; *u*, by Newberry, 1874.	J	I	H	G	F	E	D	C	B	A
"Pleurotomaria" capillaria Conrad					×					
"P" rotalia Hall					×				×	
"P" planodorsalis Hall									×	
Styliolina fissurella Hall					×				×	
Cephalopods										
Bactrites arkonensis Whiteaves										×
Orthoceras sp. A									×	
"O" sp. B		×								
"O" sp. C		×								
Tornoceras uniangulare (Conrad)										×
Trilobites										
Phacops rana (Green)	×	×			×		×		×	×
Proetus rowi (Green)		×								
Ostracods[1]										
Bairdia devonica (Ulrich)					s				s	
Barychilinia sp.									s	
Bollia sp.					s				s	
Bythocypris indianensis Ulrich					s	s		s		
B. punctatus					s				s	
Hamiltonella punctilifera (Hall)					s				s	

[1] All identifications and positions of Ostracods are those of Stauffer. No additional work on them has been attempted.

EXPLANATION OF PLATE 82

FIG. *1*—*Coenostroma pustulifera* Winchell. Distal surface, ×1, zone J, Bloomingville section, O.C.G.M. 6074.

2—*Stereolasma rectum* (Hall). Side view, ×1, zone J, Bloomingville section, O.C.G.M. 6075.

3—*Amplexus hamiltonae* Hall. Side view, ×1, zone J, Bloomingville section, O.C.G.M. 6076.

4—*Heterophrentis prolifica* Billings. Side view, ×¾, zone J, Bloomingville section, O.C.G.M. 6077.

5, 6—*Heterophrentis simplex* (Hall). *5*, Side view of average-sized specimen, ×1. *6*, View of narrow form, probably a new variety, ×1. Zone J, Bloomingville section, O.C.G.M. 6078.

7, 8—*Blothrophyllum conatum* (Hall). *7*, Side view, ×1. *8*, View of calyx, ×1. Zone J, Bloomingville section, O.C.G.M. 6079.

9, 10—*Blothrophyllum cinctutum* Davis. *9*, Side view, ×1. *10*, Calyx of larger individual, ×1. Zone J, Bloomingville section, O.C.G.M. 6080.

11—*Heliophyllum halli* Edwards and Haime. Side view, ×¾, zone J, Bloomingville section, O.C.G.M. 6081.

12—*Heliophyllum degener* Hall. View of calyx, ×¾, zone J, Bloomingville section, O.C.G.M. 6082.

13—*Heliophyllum reflexum* Hall. Side view, ×¾, zone J, Bloomingville section, O.C.G.M. 6083.

14, 15—*Heliophyllum scyphus* Rominger. *14*, Side view, ×1. *15*, View of calyx, ×1. Zone I, Bloomingville section, O.C.G.M. 6084.

16—*Heliophyllum confluens* Hall. Distal view of colony, ×¾, zone J, Bloomingville section, O.C.G.M. 6085.

17—*Eridophyllum seriale* Edwards and Haime. Side view, ×1, zone I, Bloomingville section, O.C.G.M. 6086.

18—*Eridophyllum archiaci* (Billings). View of calyx of a corallite, ×1, zone I, Bloomingville section, O.C.G.M. 6087.

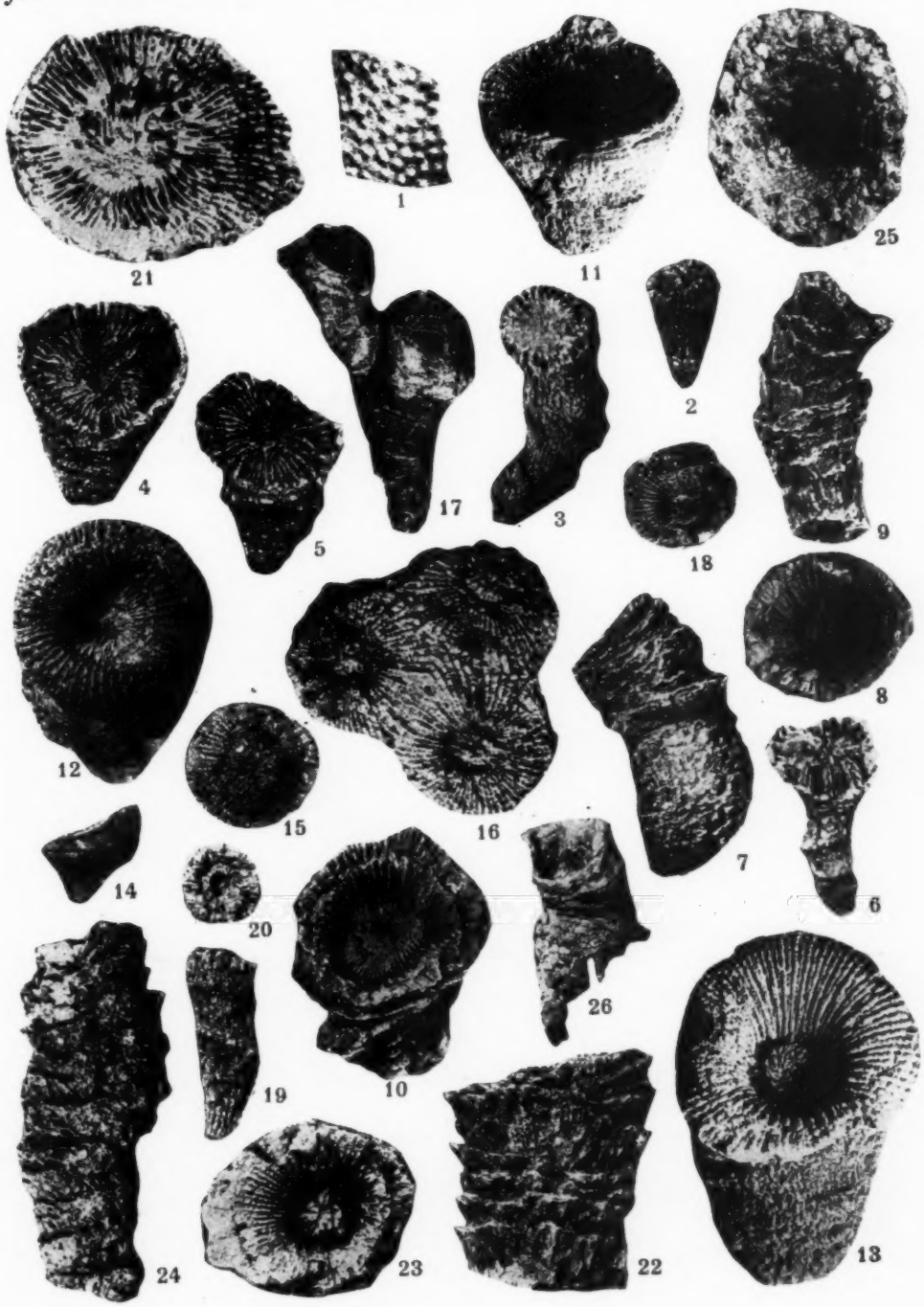
19, 20—*Eridophyllum subcaespitosum* (Nicholson). *19*, Side view, ×1. *20*, View of calyx, ×1. Zone J, Bloomingville section, O.C.G.M. 6088.

21—*Tortophyllum cysticum* (Winchell). View of calyx, ×1, zone J, Bloomingville section, O.C.G.M. 6089.

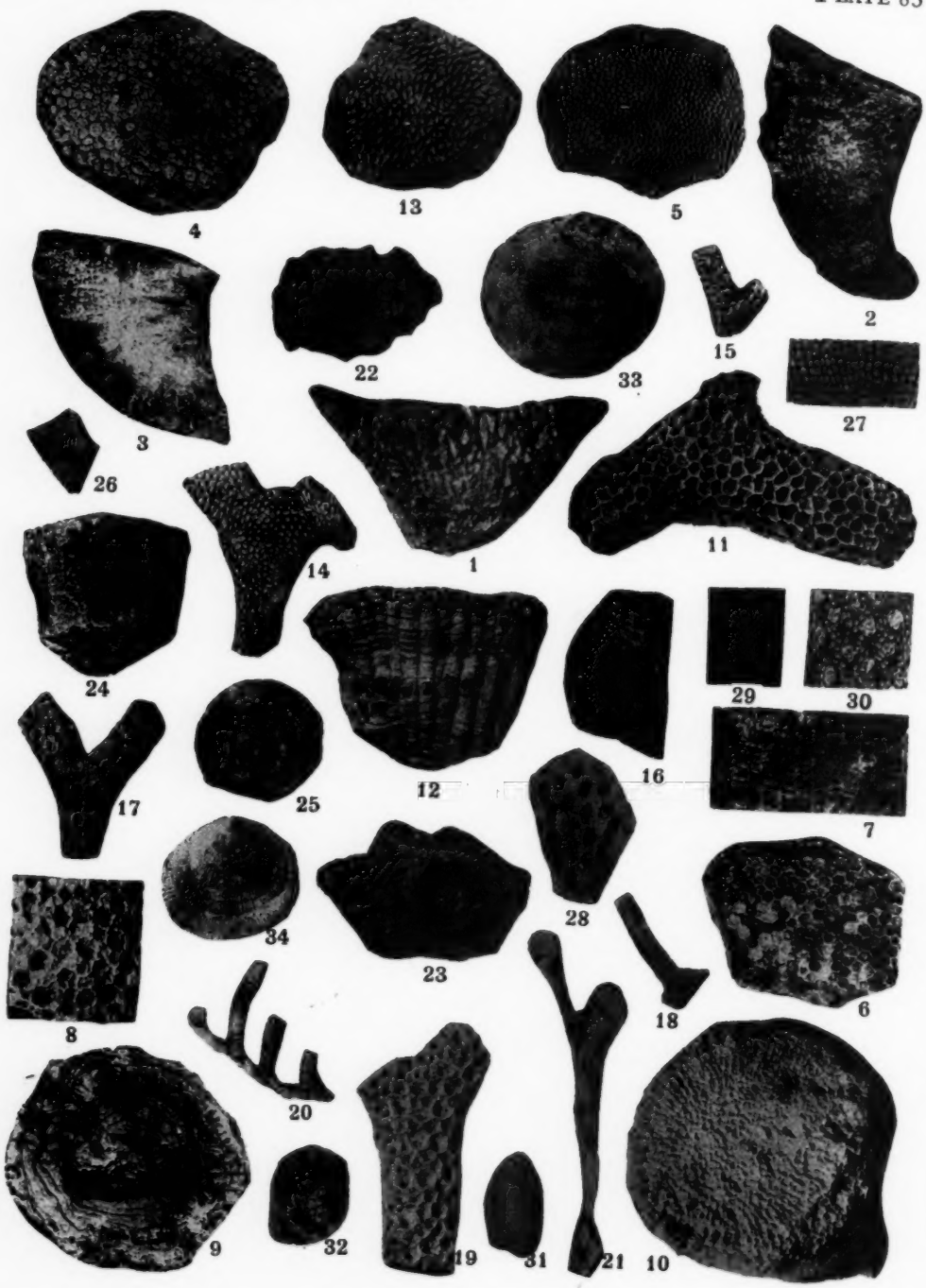
22, 23—*Acrophyllum* n. sp. *22*, Side view, ×1. *23*, View of calyx, ×1. Zone J, Bloomingville section, O.C.G.M. 6090.

24, 25—*"Cystiphyllum" vesciculosum* (Goldfuss). *24*, Side view, ×¾. *25*, Calyx of another individual, ×1. Zone J, Bloomingville section, O.C.G.M. 6091.

26—*"Cystiphyllum"* n. sp. Side view, ×1, zone J, Bloomingville section, O.C.G.M. 6092.



Stumm, Fossils of the Prout limestone



Stumm, Fossils of the Prout limestone

donta concava, S. demissa, "Spirifer" pennatus, "S." pennatus arkonensis, Leiorhynchus kelloggi, Phacops rana.		
Zone E. Soft gray shale, of which the upper foot is exposed beneath the limestone band	3±	
Characteristic species: *Chonetes setigerus, C. deflectus, "Spirifer" pennatus.*		
Zone D. Hard gray argillaceous limestone	0	6
Characteristic species: *Chonetes scitulus, C. deflectus, C. setigerus, "Spirifer" pennatus, Phacops rana.*		
Zone C. Soft gray shale, almost entirely covered	6±	
Zone B. Hard gray argillaceous limestone	0	6
Characteristic species: *Chonetes setigerus, C. scitulus, Ambocoelia umbonata, Nuculites triqueter, Nyassa recta, Phacops rana.*		

EXPLANATION OF PLATE 83

FIG. *1—Heliophyllum arachne* Hall. Side view, ×1, zone J, Bloomingville section, O.C.G.M. 6093.
2—Heliophyllum sp. Side view, ×1, zone J, Bloomingville section, O.C.G.M. 6094.
3—Aulacophyllum hemicrassatum Sloss. Side view, ×1, zone I, Bloomingville section, O.C.G.M. 6095.
4—Favosites alpenensis Winchell. Distal view of small corallum, ×1, zone I, Bloomingville section, O.C.G.M. 6096.
5—Favosites placenta Rominger. Distal surface of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 6097.
6, 7—Favosites hamiltonae Hall. *6*, Distal surface, ×¾. *7*, Side view showing tabulae, ×¾. Zone J, Bloomingville section, O.C.G.M. 6098.
8, 9—Favosites argus Hall. *8*, Portion of distal surface, ×1. *9*, Proximal surface showing peritheca, ×¾. Zone J, Bloomingville section, O.C.G.M. 6099.
10—Favosites turbinatus Billings. View of corallum, ×¾, zone I, Bloomingville section, O.C.G.M. 7000.
11—Emmonsia arbuscula (Hall). View of digitate corallum, ×1, zone J, Bloomingville section, O.C.G.M. 7001.
12—Michelinia dividua Hall. Side view of corallum, ×¾, zone J, Bloomingville section, O.C.G.M. 7002.
13—Alveolites goldfussi Billings. Distal view of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7003.
14—Cladopora fisheri (Billings). Side view of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7004.
15—Cladopora roemeri (Billings). Side view of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7005.
16—Cladopora frondosa (Billings). Side view of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7006.
17—Trachypora limbata (Eaton). Side view of corallum, ×1, zone J, Bloomingville section, O.C.G.M. 7007.
18—Trachypora elegantula (Billings). Side view of corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7008.
19—Striatopora sp. Side view of corallum, ×1, zone J, Plum Brook section, O.C.G.M. 7009.
20—Ceratopora intermedia (Nicholson). Portion of small corallum, ×1, zone J, Bloomingville section, O.C.G.M. 7010.
21—Ceratopora nobilis (Billings). Small corallum, ×1, zone I, Bloomingville section, O.C.G.M. 7011.
22—Megistocrinus rugosus Lyon and Cassidy. Base of calyx, ×¾, zone J, anticline section, O.C.G.M. 7012.
23—Dolatocrinus sp. Portion of base of calyx, ×1, zone J, Bloomingville section, O.C.G.M. 7013.
24—Arthracantha sp. Side view of internal mold of calyx, zone J, anticline section, O.C.G.M. 7014.
25—Megistocrinus ontario Hall. Internal mold of base of calyx, ×1, zone I, Bloomingville section, O.C.G.M. 7015.
26—Fenestrellina sp. B. Portion of silicified zoarium, ×1, zone J, Bloomingville section, O.C.G.M. 7016.
27—Fenestrellina sp. C. Portion of zoarium, ×1, zone J, anticline section, O.C.G.M. 7017.
28—Reteporina sp. A. Portion of zoarium, ×1½, zone I, Bloomingville section, O.C.G.M. 7018.
29, 30—Reteporina sp. B. *29*, Portion of zoarium, ×1. *30*, Same, ×3. Zone I, Bloomingville section, O.C.G.M. 7019.
31—Lingula ligea Hall. Incomplete valve, ×1, zone J, Bloomingville section, O.C.G.M. 7020.
32—Lingula thedfordensis Whiteaves. Incomplete valve, ×1, zone J, Bloomingville section, O.C.G.M. 7021.
33—Rhipidomella penelope Hall. Pedicle valve, ×¾, zone I, Bloomingville section, O.C.G.M. 7022.
34—Rhipidomella vanuxemi Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7023.

EXPLANATION OF PLATE 84

FIG. *1*—*Stropheodonta demissa* (Conrad). Incomplete pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7024.

2—*Stropheodonta concava* Hall. Internal mold of pedicle valve, ×⅔, zone I, Bloomingville section, O.C.G.M. 7025.

3—*Leptostrophia perplana* (Conrad). Internal mold of pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7026.

4—*Douvillina inaequistriata* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7027.

5—*Schuchertella arctostriata* (Hall). Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7028.

6—*Schuchertella perversa* (Hall). Portion of pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7029.

7—*Chonetes mucronatus* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7030.

8, 9—*Productella navicella* Hall. *8*, Side view, ×1. *9*, Anterior view of pedicle valve, ×1. Zone I, Bloomingville section, O.C.G.M. 7031.

10—*Productella spinulicosta* Hall. Posterior view of pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7032.

11—*Camarotoechia sappho* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7033.

12—*Camarotoechia congregata* (Conrad). Anterior view, ×1, zone I, Bloomingville section, O.C.G.M. 7034.

13—*Camarotoechia depressa* Kindle. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7035.

14, 15—*Camarotoechia thedfordensis* Whiteaves. *14*, Brachial valve, ×1. *15*, Anterior view, ×1. Zone I, Bloomingville section, O.C.G.M. 7036.

16—*Cyclorhina nobilis* Hall. Crushed brachial valve, ×1, zone I, Bloomingville section, O.C.G.M. 7037.

17, 18—*Pentamerella pavilionensis* Hall. *17*, Pedicle valve, ×1. *18*, Brachial valve, ×1. Zone I, Bloomingville section, O.C.G.M. 7038.

19–21—*Cranaena romingeri* (Hall). *19*, Pedicle valve, ×1. *20*, Side view, ×1. *21*, Brachial valve, ×1. Zone I, Bloomingville section, O.C.G.M. 7039.

22—*Cranaena* sp. Incomplete pedicle valve, ×1, zone I, Plum Brook section, O.C.G.M. 7040.

23, 24—*Eunella attenuata* Whiteaves. *23*, Brachial valve, ×1. *24*, Side view, ×1. Zone B, Bloomingville section, O.C.G.M. 7041.

25–27—*Camarophoria kernahani* (Whiteaves). *25*, Side view, ×1½. *26*, Pedicle valve, ×1½. *27*, Brachial valve, ×1½. Zone I, Bloomingville section, U. S. Nat. Mus. 99815. Homeotypes O.C.G.M. 7042.

28—"*Spirifer*" *audaculus* (Conrad). Incomplete pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7043.

29—"*Spirifer*" *pennatus* (Atwater). Incomplete pedicle valve, ×1, zone J, Bloomingville section, O.C.G.M. 7044.

30, 31—"*Spirifer*" *angustus* Hall. *30*, Posterior view. *31*, Pedicle valve, ×1. Zone I, Bloomingville section, O.C.G.M. 7045.

32—"*Spirifer*" *consobrinus* d'Orbigny. Portion of pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7046.

33—"*Spirifer*" *sculptilis* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7047.

34—"*Spirifer*" *venustus* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7048. Homeotype, zone J, anticline section, U. S. Nat. Mus.

35—*Cyrtina hamiltonensis* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7049.

36, 37—*Reticularia fimbriata* (Conrad). *36*, Internal mold of pedicle valve, ×1. *37*, Portion of small pedicle valve showing spines, ×1. Zone I, Bloomingville section, O.C.G.M. 7050.

38, 39—*Atrypa "reticularis."* *38*, Pedicle valve, ×1. *39*, Brachial valve, ×1. Zone I, Bloomingville section, O.C.G.M. 7051.

40—*Atrypa spinosa* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7052.

41—*Athyris spiriferoides* (Eaton). Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7053.

42—*Athyris vittata* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7054.

43—*Camarospira* sp. A. Internal mold of pedicle valve, ×1, zone J, Bloomingville section, O.C.G.M. 7055.

44—*Camarospira* sp. B. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7056.

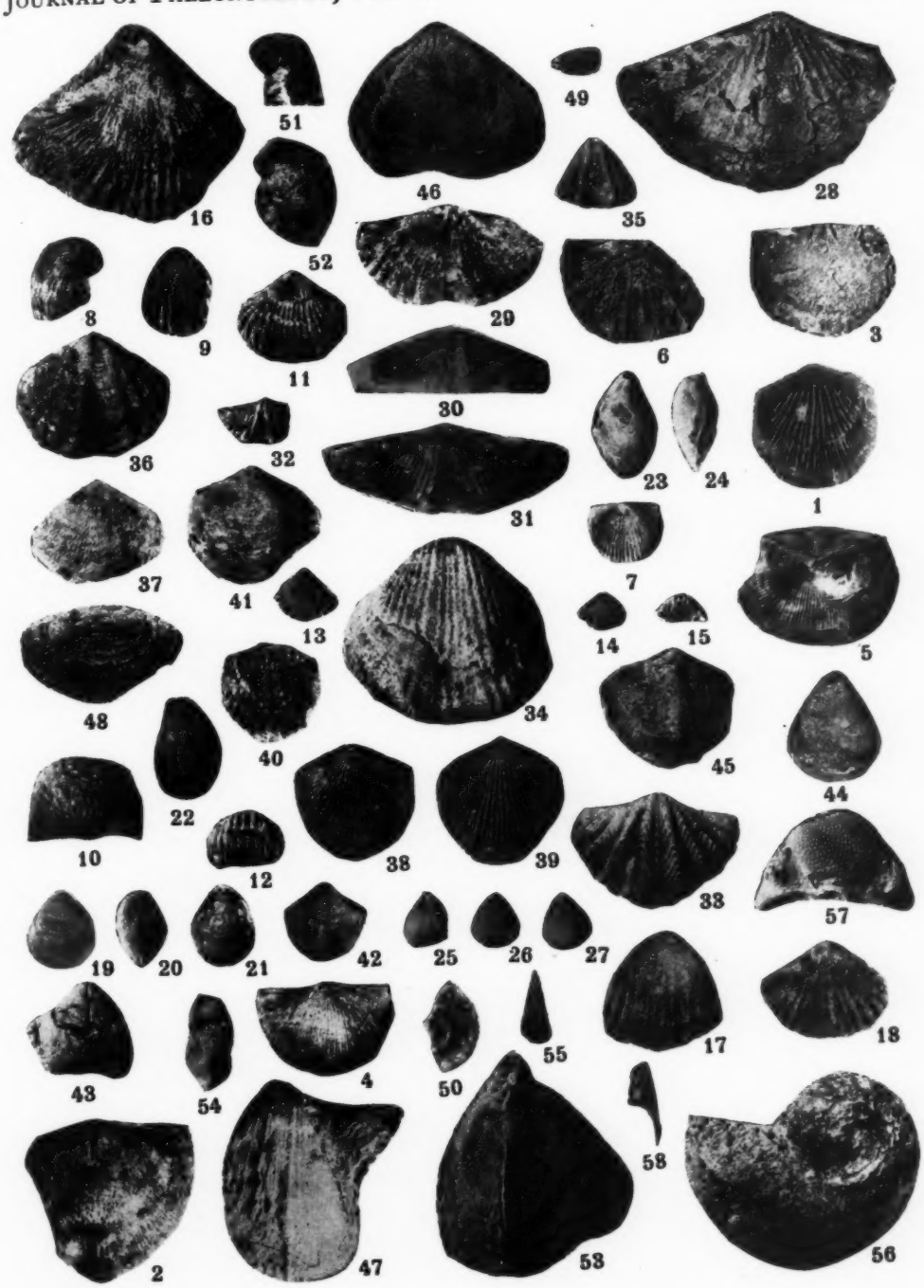
45—*Parazyga hirsuta* Hall. Brachial valve, ×1, zone I, Bloomingville section, O.C.G.M. 7057.

46—*Pentagonia bicostata* Hall. Pedicle valve, ×1, zone I, Bloomingville section, O.C.G.M. 7058.

47—*Pterinea flabellum* (Conrad). Incomplete left valve, ×1, zone I, Bloomingville section, O.C.G.M. 7059.

48—*Paracyclas elliptica* Hall. Portion of right valve, ×1, zone I, Bloomingville section, O.C.G.M. 7060.

(*Continued on page 561*)



Stumm, Fossils of the Prout limestone

UNIV. OF MICH.

Zone A. Soft gray shale, mainly covered. Weathered parts found by digging into bank. Many fossils weathered out along bank..... 10±

Characteristic species: *Ceratopora auloporoidea, Anomalotoechus* aff. *monticula, Strophеodonta demissa, Schizophoria "striatula," Leiorhynchus kelloggi, Leda rostellata, Bactrites arkonensis, Tornoceras uniangulare.*

Slate Cut section.—This section has been discussed in some detail by Prosser (1913, p. 326) and by Grabau (1917, pp. 337–338). It is in a cut of the New York Central Railroad 4 miles east of Sandusky. The section is more than 5 miles northeast of the next nearest outcrop, and it is interesting to note that the entire Prout limestone has decreased to less than 3 feet in thickness in this distance. The section is as follows:

Section in Slate Cut

	Ft.	in.
Huron shale:		
Black fissile shale.....	8±	
Prout limestone:		
Hard, siliceous grayish-brown limestone with occasional thin, somewhat shaly layers. The upper 4 inches is filled with pyrite.....	2	10
Characteristic species: *Heterophrentis prolifica, Ceratopora intermedia, Favosites hamiltonae, F. placenta, Cyclorhina nobilis, Atrypa "reticularis," "Spirifer" audaculus, Athyris spiriferoides.*		
Plum Brook shale:		
Soft gray shale, weathered to clay...	0	4

The faunal assemblage of the Prout in this section indicates that representatives of all three zones as exposed in the Bloomingville section are present. The profuse coral fauna characteristic of zone J is prevalent in the upper foot and the brachiopods of zone I are well represented toward the middle of the formation. However, no strong lithologic differences can be distinguished.

There are three other localities in which the upper part of the Prout limestone can be seen. The first is a shallow quarry on the north side of Fox Road, one-half mile east of the bridge crossing Plum Brook. Here the upper part of the Prout has been quarried out, but only the upper foot of the formation is exposed above the water now filling the quarry. This portion is a hard, cherty limestone carrying the coral fauna of zone J.

Along the south side of Fox Road, one-half mile farther east, the upper 3 feet of the Prout is exposed in a small anticlinal structure paralleling the road. In addition to the typical coral fauna of zone J, a well-preserved calyx of *Megistocrinus rugosus* and valves of *"Spirifer" venustus* and *Pentagonia bicostata* were found here.

A great number of float boulders of the upper and middle parts of the Prout can be seen along the road on Strong's Ridge for a distance from 2 to 4 miles northeast of Bellevue. This is the farthest southwest exposure of the formation, but very little can be seen in place, and none of the Plum Brook shale is now exposed.

A complete list of the species known to be in these formations is shown in the table.

CORRELATION

Stauffer (1915, pp. 9–10) correlated the Plum Brook shale with the basal shales overlying the Delaware limestone (Arkona shale) exposed at Arkona, Marsh's Mill, and Thedford, Ontario. He mentioned the pyritized association of *Leda rostel'ata, Bactrites arkonensis,* and *Tornoceras uniangulare* occurring in both formations. In 1916 (pp. 483–486), he discussed again the correlation of these shales, mentioning that this pyritized association of three fossils occurred about 25 feet below the top of both formations. He noted also that the Encrinal lime-

49—Modiomorpha concentrica? (Conrad). Small right valve, ×1, zone I, Bloomingville section, O.C.G.M. 7061.
50—Bellerophon sp. Side view of incomplete specimen, ×1, zone I, Bloomingville section, O.C.G.M. 7062.
51, 52—Platyceras erectum Hall. Side views of two specimens, ×1, zone 1, Bloomingville section, O.C.G.M. 7063.
53—Platyceras carinatum Hall. Posterior view, ×1, zone I, Bloomingville section, O.C.G.M. 7064.
54—Loxonema sp. A. Two lower whorls of incomplete spire, ×1, zone I, Bloomingville section, O.C.G.M. 7065.
55—Loxonema sp. B. Side view, ×1, zone J, Bloomingville section, O.C.G.M. 7066.
56—Diaphorostoma lineatum (Conrad). Distal view of internal mold, ×1, zone I, Bloomingville section, O.C.G.M. 7067.
57—Phacops rana (Green). Cephalon, ×1, zone J, Bloomingville section, O.C.G.M. 7068.
58—Proetus rowi (Green). Free cheek, ×1, zone I, Bloomingville section, O.C.G.M. 7069.

stone overlying the Arkona shale was lithologically similar to the Prout "especially the middle layers at Bloomingville," and stated that

> over 75 percent of the fauna of the Prout limestone also appears in the Encrinal limestone of Ontario and the upper layers contain many of the corals of the coral zone at Arkona, Ontario.

The additional species found in the Prout only serve to confirm Stauffer's correlation of these beds. The characteristic brachiopods of the basal part of the Widder formation—*Cyclorhina nobilis*, *Eunella attenuata*, *Camarophoria kernahani*, *"Spirifer" venustus*, *"S." sculptilis*, and *Parazyga hirsuta*—are all present in zone I of the Prout limestone, and the great majority of the other forms known from the Prout are also present in the Encrinal or coral zone of the Widder. In addition, most of the species found in the exposed part of the Plum Brook shale are identical with those in the Arkona. Only two characteristic species of the latter—*Microcyclus thedfordensis* and *Arthracantha punctobranchiata*—have not been found in the Plum Brook.

The Ontario beds were correlated eastward by Shimer and Grabau (1902, p. 164). They believed the Encrinal of Ontario to be equivalent to the Encrinal (Morse Creek) of the Eighteen Mile Creek section of western New York, and that this formation was the westward extension of the lower Encrinal (Centerfield) of the Livonia salt shaft in the Genesee Valley. This correlation was based largely on the presence of *"Spirifer" sculptilis* in these limestone bands at all three localities

Stauffer (1916, p. 485) agreed with Shimer and Grabau's correlation and suggested that the upper part of the Plum Brook shale might be the equivalent of the *"demissa"* bed of the Wanakah shale in the Eighteen Mile Creek section.

In 1917 (p. 946) Grabau restated this correlation, claiming that the Morse Creek limestone equalled the Centerfield limestone of the Cayuga Lake region, thereby placing his Wanakah shale in the position of the Skaneateles.

G. A. Cooper (1930, pp. 234–235) has shown that Grabau was in error in his correlation of the Morse Creek and that this formation is the westward equivalent of the Tichenor limestone of the Cayuga Lake region, and, therefore, it marks the top of the Ludlowville in the Eighteen Mile region. This correlation places the Wanakah as the equivalent of the Ludlowville. The Centerfield is stated to occur at the base of the Wanakah along Buffalo Creek, south of the Eighteen Mile Creek section, and to be represented along Lake Erie by Grabau's pteropod bed.

Both the coral and brachiopod assemblages of the Centerfield agree very closely with those found in the Prout. The brachiopods *Camarophoria kernahani*, *Eunella attenuata*, *"Spirifer" venustus* and *Pentagonia bicostata* are confined to the Centerfield in the Cayuga Lake region, and these are well represented in zone I of the Prout. The Centerfield corals are well represented in zone J. of the Prout, *Amplexus hamiltonae*, *Eridophyllum subcaespitosum*, *Emmonsia arbuscula*, *Favosites hamiltonae*, *Michelinia dividua*, and *Trachypora limbata* are especially diagnostic.

The fauna of the upper Skaneateles (Levanna) shale underlying the Centerfield agrees closely with that of the Plum Creek shale. Cooper (1933, p. 550) notes that the pelecypods *Nyassa arguta* and *Paracyclas lirata*, common at this horizon, range throughout the Skaneateles but are unknown in the Ludlowville. The Wanakah, with which Stauffer correlated the Plum Brook, carries a richer fauna including forms such as *Pleurodictyum stylopora* and *"Spirifer" granulosus*, which are unknown in the Plum Brook shale.

These faunal relationships indicate that the Prout limestone is the westward equivalent of the Centerfield limestone, and that the underlying Plum Brook shale is the equivalent of the Levanna. This correlation has been suggested by Cooper (1930, p. 123). Such an interpretation magnifies the disconformity between the Prout and the Huron shale as all the upper Ludlowville and the entire Moscow are absent in northern Ohio.

CORRELATION WITH NORTHWESTERN OHIO

Stauffer (1909) made the first comprehensive study of the beds of Hamilton age in northwestern Ohio. At that time the best exposures of these formations were along

the banks of Ten Mile Creek, ¼ mile south of Silica, Lucas County. Exposures here comprise 27 feet of dolomitic limestones becoming shaly near the base, overlying a few feet of soft grey shale, which had been dredged from the bottom of the creek. Stauffer named these beds "Traverse" because of their proximity to the Michigan deposits, and because they contain certain fossils prevalent in the Michigan deposits and unknown in northern Ohio.

In later years the base of the "soft gray shale" has been uncovered by quarries in the village of Silica. These exposures have been studied in detail by Stewart (1927, pp. 5–70; 1930, pp. 52–28; and 1937, pp. 739–763). The formation was named the Silica shale. At the quarry exposures the basal 16 feet of the formation are present, and it is estimated that about 30 feet of covered beds (mainly shale by drill records) are present between the top of the exposures at Silica and the few feet of shale at the base of the Ten Mile Creek dolomite.

Stewart (1927, p. 9) compared the Silica and Plum Brook faunas and noted that they differ greatly in their main elements. She suggested that the Silica shale might be the westward equivalent of the Prout. With this I cannot agree.

The equivalent of the Prout limestone in this region is the basal part of the Ten Mile Creek dolomite (Stauffer's 1909 zones 8 and 9). Zone 8 carries the brachiopod fauna of zone I of the Prout, including *Spirifer venustus*, and zone 9 is a coral bed almost identical with zone J of the Prout section at Bloomingville. All but three of the coral species are common to the two localities.

Of the 70 species of megafossils reported by Stewart from the lower part of the Silica shale about 22 are conspecific with Plum Brook forms, including the characteristic species *Ceratopora auloporoidea*, *Leiorhynchus kelloggi*, and *Tornoceras uniangulare*. However, the lower Silica also carries distinctive forms such as "*Spirifer*" *bownockeri* and *Leiorhynchus lucasi* that have not been found in the Plum Brook. As zone 6 of Stauffer's Ten Mile Creek section, which is apparently the top of the Silica shale, carries *Leiorhynchus kelloggi* and *Ambocoelia umbonata* in abundance, it seems that the upper Silica shale has a much closer faunal relationship to the Plum Brook.

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MOHAWKIAN RAFINESQUINAE

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ABSTRACT—The brachiopod genus *Rafinesquina* Hall and Clarke, 1892, is divisible into two genera on the basis of shell structure and interior characters. Twenty Mohawkian species of *Rafinesquina* (emended) are described, of which nine are new. A new name *R. trentonensis* is adopted for the genotype. Seven species of the new genus *Öpikina* are described, of which two are new. A second new genus *Kirkina*, with one new species, has been found in the Chazyan of Utah. Species are differentiated on the basis of the outline of the pedicle valve in ventral view and its profile in lateral view; other factors are of minor importance. All Black River species of "*Rafinesquina*" are included in *Öpikina; Rafinesquina* ranges from the Trenton through the Cincinnatian. Most of the species are not limited to one formation, but assemblages of species may be used in identifying a horizon. Various tendencies in development are observable in both genera, some species tending toward greater convexity and short radius of curvature, others toward slighter convexity, with a greater radius of curvature.

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INTRODUCTION

Nearly 50 species of the brachiopod genus *Rafinesquina* have been described from the Ordovician of North America; more than a score of these occur in the Middle Ordovician (Mohawkian). Individuals of most of the species are abundant and are found in nearly every outcrop. Morphologic and stratigraphic studies have shown that the lower Mohawkian (Black River) species heretofore assigned to *Rafinesquina* belong to another genus (*Öpikina*), not previously described or named; true *Rafinesquina* is apparently limited to the upper Mohawkian (Trenton). A second undescribed genus (*Kirkina*), which may have been ancestral to both *Rafinesquina* and *Öpikina*, has been discovered in the Chazyan of Utah.

In the course of this study, the Mohawkian species of *Rafinesquina* and *Öpikina* have been redefined or described as new. Some species, especially those longest known, had been broadly defined and were considered long ranging, whereas others, more recently described, had been considered much more limited geographically and geologically. They had been strictly defined, their specific identities usually depending upon one outstanding character. In only a few had all characters been evaluated.

In order to determine these species, a large collection of specimens from the Mohawkian of northwestern New York, southeastern Ontario and the Upper Mississippi Valley was examined in detail, and the characters of each specimen recorded. The specimens were then grouped according to similarity, some groups being identifiable with previously described species, others being apparently new. All available type specimens of known species were also studied, and their characters determined in the same manner.

The stratigraphic range of each species has been determined. It was found that some of the long-ranging species actually included forms of various sorts, which can be treated as distinct species with ranges more limited. The range of a few species was found to be more extensive than had been believed; however, the main development and greatest abundance of these forms is limited, so that their value as horizon indicators remains.

Historical Review.—The genus *Rafinesquina* was established by Hall and Clarke in 1892, with "*Leptaena alternata* Conrad" as the genotype. It was differentiated from *Strophomena* by the reversed convexity of the valves and from *Leptaena* by the muscle scars and cardinal process. Billings had already noticed in 1860 that certain species of

Strophomena had the convexity of the valves reversed from that of the normal type, and he remarked that *Strophomena alternata* was typical of this group.

At the time Hall and Clarke founded the genus, the type species was considered to include forms of both Mohawkian and Cincinnatian age, which had in common only the radiating costellae of different sizes. The specimens figured by Hall and Clarke are the Cincinnatian forms generally called *Rafinesquina alternata*, which are actually either *R. ponderosa* (Hall) or some other unnamed species.

It is proposed here to restrict the definition of the type species to a form as nearly as possible like Conrad's original material, which is believed to have come from the lower Trenton of northwestern New York State. The specific name, however, is a homonym of the British species *Heterorthis alternata* (Sowerby) = *Orthis alternata* Sowerby, 1839, in Murchison's Silurian System, p. 638, pl. 19, fig. 6, which was referred to *Strophomena* by Phillips and Salter in 1848; *Leptaena alternata* Conrad was referred to *Strophomena* by Emmons and others. On the other hand, the American species was confused with, and referred to as, *Orthis alternata* by both Conrad and Emmons. This confusion was noted by James Hall, who believed that the British species also was a strophomenid; in 1847 he reported that Conrad had proposed the name *Leptaena trentonensis* in manuscript to be used in case of conflict between the two species. It is proposed to adopt the latter name and to suppress the name *alternata* as a homonym.

Three other species now classified as *Rafinesquina* were originally described by Conrad and more fully defined by Hall in 1847, namely, *Strophomena deltoidea*, *S. camerata* and *S. tenuilineata*. Hall considered the first two practically identical, but Raymond redefined the second and resurrected it as a valid species in 1921. The third of Conrad's species has never been reported since, and Hall himself remarked that he had never seen it.

Strophomena declivis James, 1874; *Strophomena minnesotensis* Winchell, 1881; and *Strophomena inquassa* Sardeson, 1891, were also included in *Rafinesquina* by Hall and Clarke.

At least 15 other American Mohawkian species of *Rafinesquina* have been described since 1892, and similar numbers are known from the Middle Ordovician of Europe and Asia. There are equally numerous Upper Ordovician species. In recent years some of these species have been regrouped in new subgenera and genera, which will be more fully discussed below.

It has been noticed by several authors that one group of species differs sharply from the others in the characters of the interior. In America these species are represented by *Rafinesquina minnesotensis* (Winchell) and others; in Europe by the group of *R. dorsata* Bekker. In 1930 Öpik discussed this group of species at some length, remarking that they differ from *Rafinesquina "alternata"* in having strong septa limiting the muscle scars of the brachial valve and in the structure of the cardinal process; he maintained that they are connected to the typical *Rafinesquinae* through *R. inquassa* (Sardeson) (misquoted *"incrassa"*). In the course of the present study, it has been found that the shell structure of this group is also quite different from that of the other species of *Rafinesquina*. Whereas the typical *Rafinesquina* has the pseudopunctae large enough to be seen without a lens, spaced about 0.5 mm. to 2 mm. apart, and arranged in regular radial lines, the group of *R. minnesotensis* and *dorsata* has extremely fine pseudopunctae, very closely spaced over the entire shell with no apparent order, giving the shell material a finely granular appearance, which usually cannot be seen without a lens. (See text figure 1.) It is therefore believed desirable to establish a new genus, *Öpikina*, for this group of species.

Methods of study.—From each Mohawkian formation in eastern North America, the best-preserved available specimens of *Rafinesquina* were selected for study, and the following characters described for each specimen:

Outline, or shape in ventral view (exterior view of pedicle valve normal to the commissure).
Convexity, or shape in lateral view.
Number of primary costellae at a growth stage ½ inch from the beak and at the periphery of the specimen.
Number of secondary and tertiary costellae between the primaries, at the same stages.

General character of all the costellae—whether relatively coarse or fine.
Character of the concentric lines—relative size and spacing.
Presence or absence and extent of diagonal or concentric wrinkles.
Presence or absence and character of growth lines.
Size, spacing, and arrangement of pseudopunctae.
Position of the geniculation, or point of greatest convexity.
Character of geniculation—whether angular or rounded, and degree of slope.
Width of the shell at the hinge line and at 3 mm. intervals along lines parallel to the hinge (measurements taken at the 15 mm. growth stage).
Length of shell along the median line and along a parallel line from a point halfway between the beak and the cardinal extremity.
Interior structures when visible.

The most important characters are those of the interior (especially the brachial) and the shell structure (character of the pseudopunctae). These are considered fundamental and are here used as generic distinctions. This usage is in accord with recent research in other groups of brachiopods, notably the work of Schuchert and Cooper on the Orthoidea.

A less fundamental character is the shape of the shell in lateral view: whether it has a long, gentle arc of curvature, producing low convexity, or has a sharp curvature (geniculation) at some point. It is important to note the character of the geniculation (whether angular or rounded), its position, and the degree of slope of the anterior section of the shell with respect to the posterior section. The position of the geniculation should always be given in absolute measurements, not relative to the length, since the shell grows only at the margins, and the point of geniculation, once established, remains fixed, while the length of the shell increases with age. Thus, in a specimen 20 mm. long, if the geniculation occurs at a point 10 mm. from the beak, it would be situated at one-half the length of the shell, whereas if the specimen had been able to add five more millimeters to its length before death, one would say that the geniculation occurred at two-fifths the length of the shell. Specimens otherwise alike have been placed in different species on the basis of such statements of relative position of the geniculation, but when the position was measured in millimeters, it was found to occur at the same distance from the beak in both shells. The two specimens compared probably represent different growth stages of the same species.

Of equal importance to the convexity is the outline of the shell in ventral view: whether the cardinal angles are acute, obtuse, or rectangular; the lateral margins sinuate, evenly curved or nearly straight; the anterior margin broadly or narrowly rounded; and whether the lateral margins join the anterior without a change of curvature or form an anterolateral angle.

The two characters discussed—convexity and outline—are here considered the basic criteria for distinguishing species.

The surface characters—costellae, concentric lines and wrinkles or rugae—are considered to be of minor importance and subsidiary to the more fundamental characters. The radial costellae in general seem to be differentiated in size on almost all specimens, although the differences in size are more strongly marked in some species than in others. This character, together with the relative coarseness of all the costellae of a specimen, seem to be directly dependent upon the shell structure, since the specimens of the group of *R. minnesotensis* and *dorsata*, with finely granular shell structure, all have relatively fine costellae, while specimens with coarsely pseudopunctate shell structure, such as *R. trentonensis*, have coarse costellae. The same is true of the concentric lines, which are fine and almost invisible in the *R. minnesotensis* group, but strong and easily visible in the true *Rafinesquinae*.

No regularity could be observed in the "alternation" of the costellae; so far as known, there is no symmetry in the number of secondary costellae between the primaries on a single specimen, nor consistency among specimens which from all other appearances belong to the same species. The number of finer costellae between any two primaries on a single specimen is apparently entirely fortuitous and probably arises from the distribution of papillae on the mantle of the individual animal, differing for each specimen somewhat in the manner of fingerprints.

Rugae are likewise not dependable as a specific character; some species show more tendency for individuals to develop rugae than do others, but within the species itself

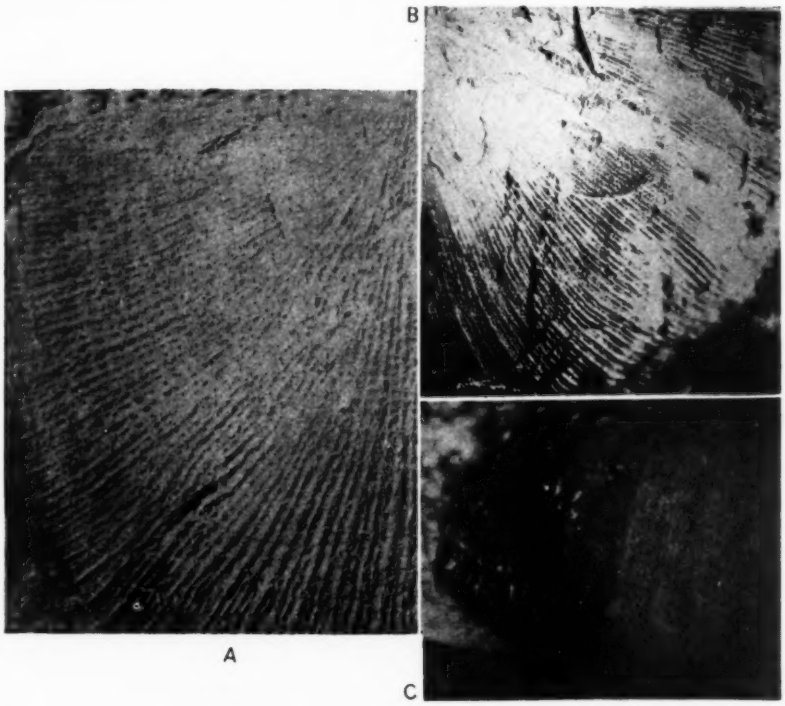

FIG. *1*—Shell structures of *Rafinesquina*, *Strophomena* and *Öpikina*. *A*, *Rafinesquina*, ×±4; *B*, *Strophomena*, ×±4; *C*, *Öpikina*, ×±6.

the presence and relative strength of the rugae are variable. Rugae cannot be correlated with the presence of auriculations ("ears") at the cardinal extremities, since many specimens with ears show no rugae, and on specimens which do show rugae, the growth lines and concentric lines parallel the shape of the cardinal angle and in so doing cut diagonally across the rugae.

The presence of heavy growth lines is apparently dependent upon the ontogenetic stage of the individual; growth lines are actually represented over the whole shell by the fine concentric lines but usually become prominent only in the later growth stages, occurring generally around and anterior to the area of greatest curvature or around the margins of large specimens of low convexity.

Attempts were made early in the course of this study to classify the specimens into species by statistical methods on the basis of the measurements obtained. In each case a group of specimens from one horizon was used, among which several different sorts could be distinguished by casual observation. Several combinations of measurable characters were used, with the objective of showing in graphic form the observable differences in appearance.

The outline of the shell in ventral view was one of the first characters used. The outline of the 15 mm. growth stage was obtained on each specimen by measuring 15 mm. from the beak along the median line and then marking in white pencil, under the microscope, along the concentric line at that point. This gave the outline of the shell at the stage when its median length was 15 mm. The 15 mm. growth stage was selected because it was desired to measure all shells at the same stage of growth, and because most shells available were at least 15 mm. long, but many of them were not much longer, and if a later growth stage had been selected, many specimens would have been excluded from consideration.

After obtaining the outline of the shell

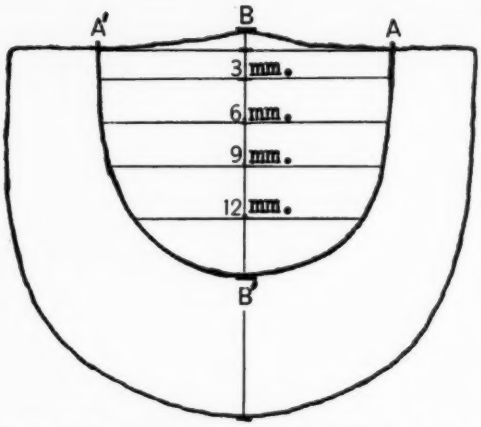

FIG. 2—Diagram showing the outline of the 15 mm. growth stage on a specimen of *Rafinesquina* and the positions of lines along which measurements of width were taken. *A-A'*, hinge width; *B-B'*, median length; *A-B'-A'*, outline of 15 mm. growth stage.

at the 15 mm. growth stage, the width of the hinge line at that growth stage was measured, and the width of the shell along lines parallel to the hinge line and spaced 3 mm. apart. (See text figure 2.) These measurements of width were then expressed as ratios, using the median length (15 mm.) as unity. When plotted on a graph, these ratios produce a curve which roughly approximates the outline of one side of the specimen. Specimens which by simple observation appeared to be conspecific produced curves which closely corresponded. However, specimens having similar outlines but quite different convexity also produced like curves. Text figure 3 shows the curve produced by plotting the measurements of two specimens, one of which was later classified as *R. deerensis*, the other as *R. normalis*. The measurements of width, and therefore the ratios of width to length, were alike in both specimens, although the specimen of *R. deerensis* has definite anterolateral and median angles, while the specimen of *R. normalis* is oval in outline. The two specimens also differ considerably in convexity. The specimen of *R. normalis* is only moderately convex, with a gently rounded posterior section and a short, sloping anterior section, the geniculation occurring at 22 mm. from the beak (the entire specimen is 24 mm. in length). The specimen of *R. deerensis* is highly convex, with a nearly rectangular geniculation occurring at 15 mm. from the beak (the entire specimen is 20 mm. in length). This basis of classification must therefore be rejected.

Another type of graph used is shown in text figure 4, in which the hinge width of the 15 mm. growth stage was compared with the width of that stage measured at 9 mm. from the beak. It may be seen from figure 4 that the different species used tend to be grouped in certain areas of the graph, but that their fields overlap to a considerable extent; in several cases, the points of specimens belonging to two or even three different species are identical, although the specimens themselves are distinguishable. This is a result of the fact that such a graph does not express the *shape* of the lateral margins, but only the amount of divergence between them, nor is the convexity of the specimen taken into account. For this reason, the same suite of specimens, when plotted on this type of graph without labels, could not be divided into groups; it is only possible

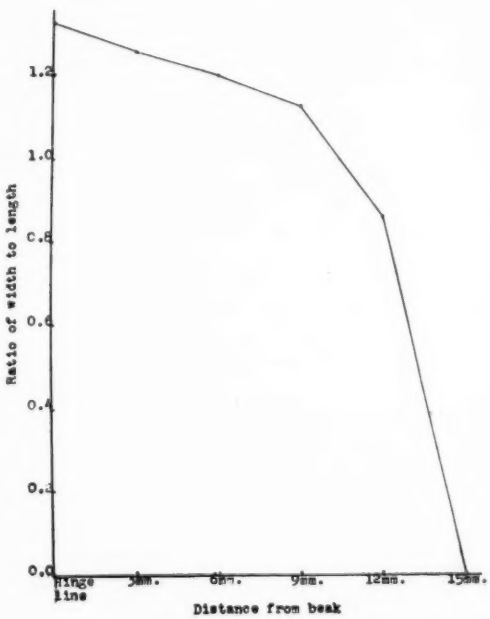

FIG. 3—Graph showing identical curve produced by plotting the ratios of width to length at the hinge line and at intervals of 3 mm. from the beak, on a specimen of *R. normalis* and a specimen of *R. deerensis*.

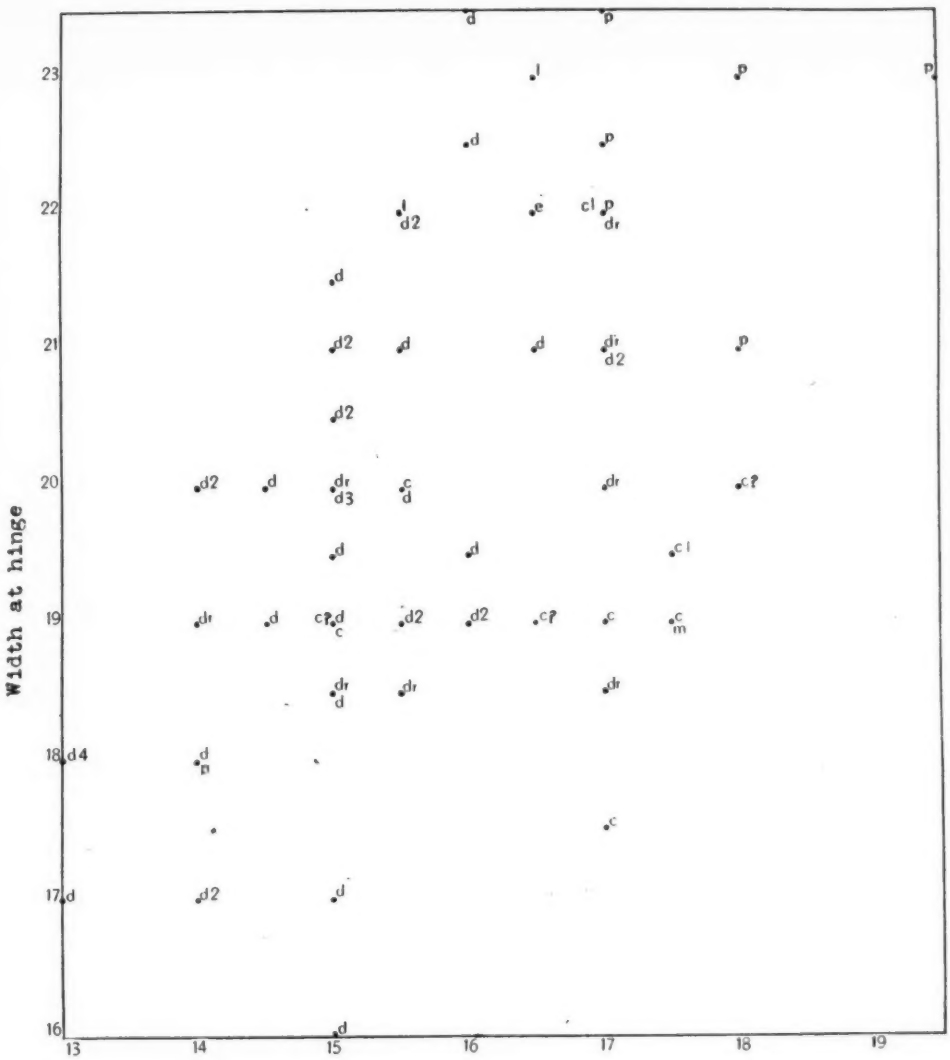

FIG. 4—Graph showing hinge width and width at 9 mm. from beak (measured in millimeters) of all lower Cobourg specimens studied. l, *R. lewisensis;* e, *R. equipunctata;* cl, *R. carlottina?;* m, *R. minuta?;* c, *R. camerata;* dr, *R. deerensis?;* d, *R. deltoidea;* p, *R. praecursor.*

to observe the fields of the different species after they have been identified by other means.

The hinge width at the 15 mm. growth stage compared with the position of the geniculation in millimeters from the beak was plotted, with the same results. The fields of the different species overlapped, and the outline of the shell and angle of the geniculation could not be expressed, so that the grouping of the specimens according to species was only discernible after the specimens had been identified by other means and labelled on the graph.

It was therefore concluded that, while the statistics gathered were useful as a part of

the description of a species already established on the basis of its general appearance, there are too many factors involved in the differentiation of species to permit their expression in a two-dimensional graph in such a manner that a specimen may be identified by its location on the graph.

Acknowledgments.—The writer is indebted to Dr. G. M. Kay of Columbia University, under whose direction this study has been carried out, and whose advice and criticism have been invaluable throughout its progress. She thanks Dr. H. N. Coryell of Columbia University for his encouraging interest and helpful comments; Dr. G. Arthur Cooper of the United States National Museum for assistance and instruction in the preparation of the plates and for the use of specimens at the Museum as types; Dr. Alice Wilson of the Geological Survey of Canada for specimens of some of her species and for comparing some of the writer's specimens with types in the National Museum of Canada; Dr. A. C. Macfarlan of the University of Kentucky for topotypes of *Rafinesquina winchesterensis;* Dr. A. Öpik of the University of Tartu, Estonia, for topotypes of *R. dorsata* and excellent specimens of several other Estonian species; and Dr. Kenneth Caster and Mr. George Rozanski of the University of Cincinnati for a large suite of Cincinnatian Rafinesquinas.

Type material was also borrowed from The American Museum of Natural History, the University of Chicago, Yale University, the University of Minnesota, and McGill University. Plastotypes were obtained from the United States National Museum.

A part of the material studied was collected by the writer during the summers of 1935 and 1936; it is incorporated in the Ordovician collections in the Department of Geology at Columbia University, which furnished the remainder of the specimens used.

SYSTEMATIC DESCRIPTIONS

Superfamily STROPHOMENACEA

Family STROPHOMENIDAE

Subfamily RAFINESQUININAE

Genus RAFINESQUINA Hall and Clarke, emended

Leptaena (part), *Strophomena* (part), *Orthis* (part), *Streptorhynchus* (part), authors.

Rafinesquina (part) HALL and CLARKE, *1892*, New York Geol. Survey, Palaeontology, vol. 8, pt. 1, p. 281; WINCHELL and SCHUCHERT, *1893;* CUMINGS, *1908;* GRABAU and SHIMER, *1909;* ÖPIK, *1930.*

Rafinesquina, FOERSTE, *1910;* RAYMOND, *1921;* BASSLER, *1932;* WILSON, *1932.*

?Rafinesquina, WELLER, *1903.*

Not *Rafinesquina*, RUEDEMANN, *1901.*

Not *Rafinesquina* Hall and Clarke, emend. BANCROFT, *1929.*

Playfairea REED, *1917*, Royal Soc. Edinburgh Trans., vol. 51, p. 866 (genotype, *Strophomena deltoidea* Conrad).

?Kjaerina BANCROFT, *1929*, Manchester Literary and Philos. Soc. Mem. Proc., vol. 73, no. 41, p. 43 (genotype, *Kjaerina typa* Bancroft, by original designation).

?Hedstroemina BANCROFT, *1929*, idem, p. 56 (genotype, *Hedstroemina fragilis* Brancroft, by original designation).

Not *Bekkerella* (subgenus of *Rafinesquina*) REED, *1936*, Palaeontologia Indica, n. ser., vol. 21, pt. 3, p. 38 (subgenotype: *Orthis subcrateroides* Reed, 1906, by original designation).

Genotype, *Rafinesquina trentonensis* (Conrad) = *Strophomena alternata* Conrad in Emmons, 1842 (homonym of *Orthis alternata* Sowerby, 1839) = *Leptaena trentonensis* Conrad in Hall, 1847, by original designation.

Concavo-convex; surface ornamented by radiating costellae differentiated in size, and by fine concentric lines representing growth lines. Cardinal margins not denticulate.

The shell structure, as in all Strophomenacea, is pseudopunctate. The pseudopunctae are relatively large, ranging from barely to easily visible with the naked eye, and placed from 0.5 mm. to 1 mm., or even 2 mm. apart, arranged in well-defined radial rows corresponding to the striae (grooves between the costellae) of the exterior surface. The pseudopunctae appear as inwardly directed pits (when weathered) in the intermediate layers of the shell, and as pustules on the inner surface, easily visible and projecting rather sharply. They are not present in the outer layers of the shell and cannot be seen on unweathered specimens except after exfoliating a small area of the surface and applying weak hydrochloric acid. (See text figure 1.)

The costellae of the exterior are not present on the interior surface of the shell. However, many internal molds have the exterior ornamentation impressed upon them or retain a few thin shell layers, since the shell is exceedingly thin in some species, and

the costellae are present throughout the median and exterior layers. This has led some authors into error. However, silicified specimens cleared of matrix show no costellae upon the interior surface.

The interior of the brachial valve is strongly pustulose in all species. The brachiophores are short and narrow, situated on the posterior sides of a pair of curving ridges of adventitious shell material, which is fused to the notothyrial platform. A median ridge extends from the notothyrial platform anteriorly about 5–8 mm. The median ridge, notothyrial platform, and ridges of adventitious shell substance form an anchor-shaped mass that is very characteristic of the rafinesquinid brachial interior; the angle between the arms of the anchor varies among the species from 45° to 90°. The adductor scars are not differentiated in the type and other primitive species; in higher species, however, a broad, low swelling or a ridge separates the posterior from the anterior adductor scars, extending anteriorly to the same extent as the median ridge. In a few species the median ridge is extended farther, but in a much attenuated form, and there may be a second pair of lateral ridges arising from the anterior ends of the first pair, but offset slightly toward the median line. Text figure 5 shows the primitive type of brachial interior (5a); a rather complex type whose elements are, nevertheless, delicate and sharply defined (5b); and another complex type characterized by the massiveness of its elements (5c).

The muscle area of the pedicle valve does not usually exceed one-half the valve's length. It becomes longer in proportion to the size of the shell in the higher Trenton and Cincinnatian species than it is in the lower Trenton forms. It varies from fan-shaped or subcircular to elongate and hexagonal, with radial ridges; the boundaries are usually very faintly indicated. Beyond the muscle area, both valves show radial lines of pustules, and occasionally vascular markings.

Discussion.—In 1917 Reed established the subgenus *Playfairea*, designating "*Leptaena deltoidea* Conrad" as the subgenotype. The subgenus was differentiated from *Rafinesquina* s.s.

by the smallness of the diductors in the pedicle valve, and by the internal characters of the brachial valve being almost identical with *Leptaena*.

Kay showed in 1935 that *Rafinesquina deltoidea* (Conrad) does not have a

small subcircular or subpentagonal muscle-scar, about one-fourth the length of the valve, but possesses a much larger one similar to that in other species of *Rafinesquina*.

He therefore placed *Playfairea* in synonymy with *Rafinesquina*. The writer has observed that the pedicle muscle scars in *Rafinesquina deltoidea* and other allied species, such as *R. praecursor* Raymond, occupy about one-third to one-half the length of the shell (extending to the geniculation), and differ from the fan-shaped muscle area of *R. trentonensis* in being elongate and narrowed anteriorly, with the adductor tracks extending somewhat beyond the margins of the diductor scars. The general shape of the muscle area thus tends toward hexagonal.

Reed has given the new name *R. girvanensis* to his misidentified specimens of *R. deltoidea;* the genus or subgenus to which they belong, if not *Rafinesquina* s.s., should also have a new name, since the name *Playfairea* belongs to the true *R. deltoidea*.

Hedstroemina and *Kjaerina* Bancroft, 1929, seem to be essentially equivalent, since they differ from each other only in the amount of curvature in the brachial valve, and in the presence of conspicuous mesial "ribs" on the pedicle valve of *Kjaerina*. These characters, as has been pointed out above, seem to the writer to be of only specific value; it therefore seems illogical to separate two genera on these bases. Bancroft's genera are said to differ from *Rafinesquina* in the shape of the muscle scars of the pedicle valve—the muscle area in *Rafinesquina* is said to be subcircular or fan-shaped, while those of *Kjaerina* and *Hedstroemina* are said to "taper in front of the dental plates" and to assume a "hemi-hexagonal form." As remarked in connection with *Playfairea*, muscle scars of this shape have been observed in *Rafinesquina deltoidea* and *R. praecursor*. If it seems necessary to separate species having this type of muscle scar from *Rafinesquina* s.s. they must be called *Playfairea*, since *R. deltoidea* is the type of that subgenus, and the name has precedence over *Kjaerina* and *Hedstroemina*

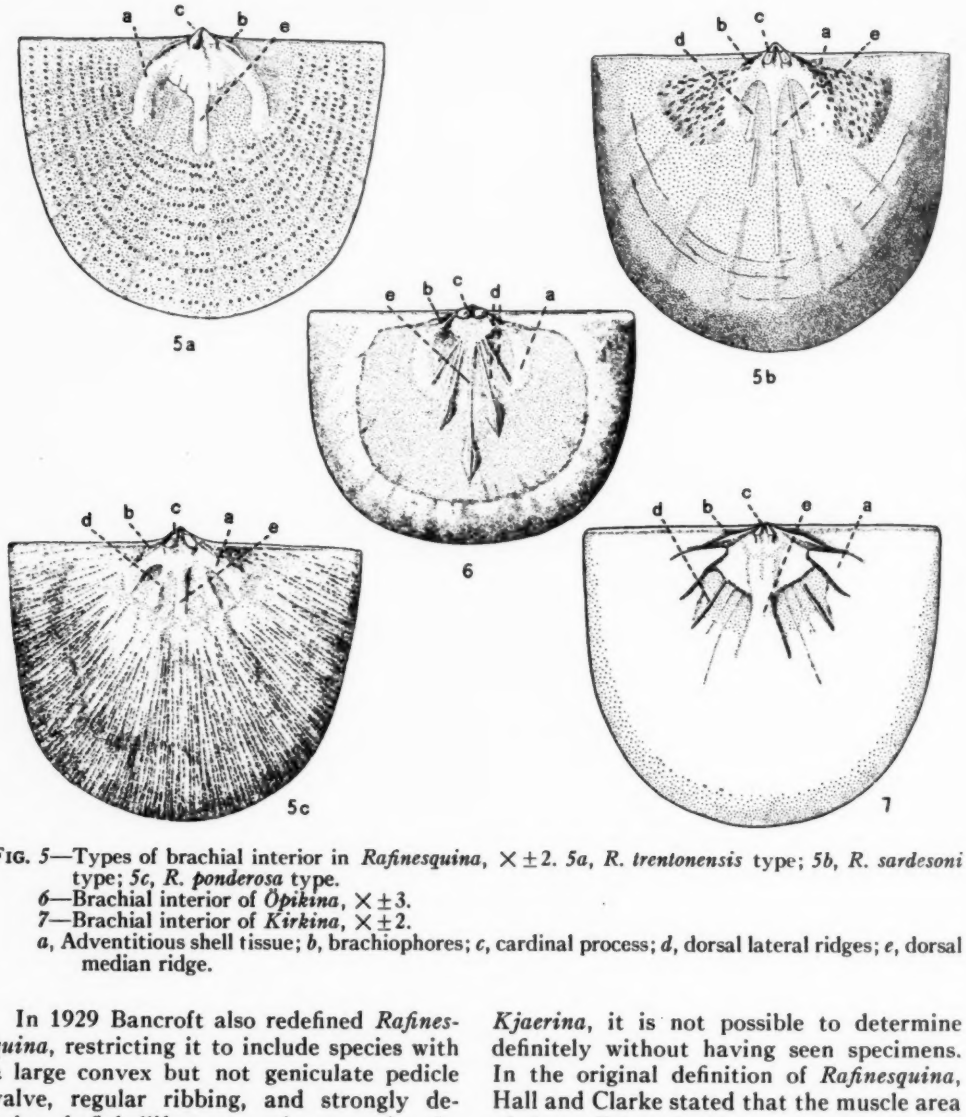

FIG. 5—Types of brachial interior in *Rafinesquina*, ×±2. *5a*, *R. trentonensis* type; *5b*, *R. sardesoni* type; *5c*, *R. ponderosa* type.
6—Brachial interior of *Öpikina*, ×±3.
7—Brachial interior of *Kirkina*, ×±2.
a, Adventitious shell tissue; *b*, brachiophores; *c*, cardinal process; *d*, dorsal lateral ridges; *e*, dorsal median ridge.

In 1929 Bancroft also redefined *Rafinesquina*, restricting it to include species with a large convex but not geniculate pedicle valve, regular ribbing, and strongly developed flabelliform muscle scars in the pedicle valve. Bancroft stated that neither *Rafinesquina* nor *Kjaerina* develop pustules on the interior surface of the valves, whereas *Hedstroemina* does. However, the figures of *R. "alternata"* cited by him (the Cincinnatian forms figured by Hall and Clarke) show distinct pustules in radial rows on the interior surface; pustules are also present in the genotype, *R. trentonensis*, and all other species of *Rafinesquina* observed by the writer. As for the lack of pustules in *Kjaerina*, it is not possible to determine definitely without having seen specimens. In the original definition of *Rafinesquina*, Hall and Clarke stated that the muscle area of the pedicle valve is not strongly limited —a statement that has been found to hold for all the species of *Rafinesquina* studied. Bancroft's redefinition is therefore directly contradictory to both the original definition of the genus and the characters possessed by the type and other species. His emendation was based upon figures of specimens not conspecific with the type, which were, in addition, misinterpreted by Bancroft.

The subgenus *Bekkerella* Reed, 1936, is apparently not congeneric with *Rafinesquina*.

There is no formal description of *Bekkerella*, but two species are assigned to it, one of which is said to have a crenulated hinge line, although there are also teeth in the pedicle valve. It is impossible to reach a conclusion without seeing Reed's specimens, but it appears from the descriptions and illustrations that *Bekkerella* is more closely allied to *Stropheodonta* than to *Rafinesquina*.

Since *Rafinesquina* is here restricted to include only those species that have coarsely pseudopunctate shell structure and at most three radial ridges in the brachial valve, a part of the species assigned to this genus by previous authors must be withdrawn from the synonymy. Those which have a finely granular shell structure and five radial ridges in the brachial interior belong to *Öpikina*.

Rafinesquina differs from *Leptaena* in having the muscle area of the pedicle valve faintly marked, whereas *Leptaena* has strong borders around the muscle scars; the cardinal process is more closely sessile in *Rafinesquina*, and in some species (of Cincinnatian age, which may belong to the genus *Longvilleia*), there is a small septum-like process between the lobes. The shape of the brachial muscle scars and the disposition of the septa are different from those of *Leptaena*. *Rafinesquina* does not differ from *Leptaena* in shell structure, since *Leptaena* also has coarse pseudopunctae, arranged far apart and in rows. The species of *Leptaena* usually have strong concentric rugae on the posterior portion of both valves, especially around the geniculation. One species of *Rafinesquina*, *R. deltoidea*, shows similar concentric rugae, but they are not always present, and are much stronger on the brachial valve than on the pedicle. In addition, *R. deltoidea* has a subtriangular outline, whereas the species of *Leptaena* have a very different outline, usually much wider than long, with the anterolateral angle sharply marked and generally about 90°.

Range.—*Rafinesquina* has long been quoted as ranging from the Chazyan to the lower Silurian. The writer has examined all the available specimens of so-called *Rafinesquina* in the paleontological collections of Columbia University and a number of types loaned by other institutions, and has not seen any *Rafinesquina* from rocks older than Trenton. It is therefore believed that, at least in northeastern United States and eastern Canada, *Rafinesquina* makes its first appearance in the Rockland formation, and that Black River and older species of this general area assigned to *Rafinesquina* belong to other genera.

There seems to be no question as to the Trenton—Richmond range of *Rafinesquina;* although the forms present in the Upper Ordovician are not conspecific with those of the Trenton, some of them, at least, are apparently congeneric. The writer has not investigated the lower Silurian species.

Artificial Key to the Species of Rafinesquina

A. Not geniculate: greatest curvature at umbo.[1]
  1. Convexity low; nearly straight from umbo forward ..... *trentonensis*
  2. Convexity moderate; broadly curved from umbo forward, lessening in steepness toward anterior.
    a. Outline narrow elongate U-shaped, with narrow extended ears ..... *elongata*
    b. Outline elongate rounded U-shaped, without ears ..... *lennoxensis*
  3. Convexity moderate, with rather narrow continuous curvature to anterior ..... *olliformis*
  4. Convexity high; continuous sharp curve from umbo forward.
    a. Long radius of curvature—shell large ..... *robusta*
    b. Short radius of curvature—shell very small ..... *minuta*

B. Geniculate: sharpest curvature at some point anterior to umbo.
  1. No definite angle; strongest curvature about 9 mm. from beak ..... *prestonensis*
  2. Angle between posterior and anterior sections about 160°.
    a. Posterior flattened; sharpest curvature 18–20 mm. from beak ..... *lewisensis*
    b. Posterior gently rounded; sharpest curvature 20–25 mm. from beak ..... *winchesterensis*
  3. Angle between posterior and anterior sections about 120°.
    a. Geniculation about 12 mm. from beak, not angular ..... *carlottina*
    b. Geniculation about 15 mm. from beak, sharply angular.
      (1) Outline modified deltoid—broad ..... *deerensis*
      (2) Outline U-shaped to V-shaped—narrow ..... *declivis*
    c. Geniculation about 18 mm. from beak.
      (1) Outline ovate, narrow; geniculation rounded ..... *praecursor*

[1] "Umbo" is here used to mean the apex of the swollen area immediately anterior to the beak.

(2) Outline deltoid, subpentagonal; geniculation sharply angular..... ..... *deltoidea*
(3) Outline triangular, geniculation rounded..... *normalis*
d. Geniculation about 20 mm. from beak.. ..... *edmondensis*
e. Geniculation about 25 mm. from beak ..... *equipunctata*
f. Geniculation about 30 mm. from beak ..... *ponderosa*
4. Angle between posterior and anterior sections about 90°.
a. Geniculation about 9–12 mm. from beak ..... *camerata*
b. Geniculation about 18–20 mm. from beak..... *sardesoni*

RAFINESQUINA TRENTONENSIS (Conrad), emended

Plate 85, figures 1–10

Leptaena alternata CONRAD, *1838*, New York Geol. Survey Second Ann. Rept., p. 115 (nomen nudum).
Strophomena alternata CONRAD, *1839*, *idem*, Third Ann. Rept., p. 63 (nomen nudum).
Strophomena alternata CONRAD, *1840*, *idem*, Fourth Ann. Rept., p. 201 (nomen nudum; listed as *S. alternata* Sowerby).
Strophomena alternata CONRAD, *1841*, *idem*, Fifth Ann. Rept., p. 37 (nomen nudum).
Orthis alternata EMMONS, *1842*, Geology of New York, pt. 2, pp. 182, 319 (no description; refers to p. 395 for figure and description).
Strophomena alternata EMMONS, *1842*, *idem*, p. 395, fig. 3.
Orthis plana CASTELNAU (not Pander), *1843*, Essai sur le système silurien de l'Amérique septentrionale, p. 38, pl. 14, fig. 1.
?Orthis huroniensis CASTELNAU, *1843*, *idem*, p. 37, pl. 14, fig. 6.
?Strophomena angulata? OWEN, *1844*, Report of a geological exploration of part of Iowa, Wisconsin, and Illinois . . . in 1839, pl. 18, figs. 1, 3 (misprint for *alternata*).
Strophomena alternata, OWEN, *1844*, Am. Jour. Sci. ser. 1, vol. 47, p. 366, fig. 3 (copy of Emmons' figure, 1842).
Leptaena alternata, HALL, *1847* (part), Palaeontology of New York, vol. 1, p. 102, pl. 31, figs 1a–c; pl. 31A, figs. 1d–e.
Leptaena trentonensis Conrad MS. HALL, *1847*, *idem*, p. 102, footnote (new name for *L. alternata* Conrad).
Strophomena alternata (part), EMMONS, *1855*, American geology, vol. 1, pt. 2, p. 197, pl. 11, fig. 3 (lower); pl. 17, fig. 2.
Strophomena alternata, BILLINGS, *1856*, Canadian Naturalist and Geologist, vol. 1, p. 204, fig. 3.
Strophomena alternata, E. HITCHCOCK, *1861*, Report on the geology of Vermont, vol. 1, p. 293, fig. 199.
Strophomena alternata (part), LESLEY, *1890*, Pennsylvania 2d Geol. Survey Rept. P4, p. 1121, figs. (only the figure copied from Emmons, 1842).
Rafinesquina alternata, WINCHELL and SCHUCHERT, *1893*, Minnesota Geol. and Nat. History Survey Final Rept., vol. 3, pt. 1, p. 404, pl. 31, figs. 32–33, 34(?).
Rafinesquina alternata, (part), CUMINGS, *1908*, Indiana, Div. Geology, Thirty-second Ann. Rept., p. 926, pl. 37, fig. 1b (copied from Emmons, 1842).
Rafinesquina hermitagensis BASSLER, *1932*, Tennessee, Div. Geology, Bull. 38, pp. 76, 80, 206, pl. 12, figs. 5–6 (not described).
Rafinesquina hermitagensis, BASSLER, *1935*, Washington Acad. Sci. Jour., vol. 25, no. 9, p. 406.
Not *Strophomena alternata* and *Rafinesquina alternata* of other authors.

Conrad's specimen or specimens on which he based this species are apparently lost. There are no specimens resembling the species among Conrad's collections at the Philadelphia Academy of Sciences; they were probably incorporated in the Hall collections, but they are not now identifiable as Conrad's. The same applies to any specimens which Emmons may have had. It appears necessary to choose a new type specimen for *Rafinesquina trentonensis*, with the provision that if a specimen of this species is ever located which unequivocally belonged to Conrad or to Emmons, that specimen shall have precedence.

The specimen selected must necessarily come from the horizon and locality mentioned by Conrad and by Emmons, Trenton limestone of Jefferson County, New York, and should if possible be a specimen which either of those men may have seen. It must also closely resemble the original figure given by Emmons.

Such a specimen exists in the Hall Collection in the American Museum of Natural History, New York City. This specimen was figured by Hall in Vol. 1 of the Paleontology of New York, pl. 31, fig. 1a, and with many other figures accompanied the first thorough description of the species. The specimen in question, Am. Mus. No. 25298, bears the label "Trenton limestone, Watertown, New York"; Watertown is located in Jefferson County. Other specimens have been collected by the writer from Sacket Harbor, about 10 miles west of Watertown, which are apparently identical with Hall's specimen. The horizon of these specimens is the Hull formation of the Trenton group. The emended description of *Rafinesquina trentonensis* is drawn from Hall's specimen,

the neotype of the species, and from these topotypes.

Emended description.—Wider than long, broadly U-shaped in outline, greatest width at or near the hinge line. Cardinal angles usually rectangular, but may show small ears or may be slightly obtuse. Lateral margins usually straight and parallel; when the cardinal angles are auriculate, the lateral margins are faintly sinuate anterior to the ears. The anterolateral and anterior margins form a broad, smooth curve, varying only slightly from perfectly semicircular.

The convexity is very low; the sharpest curvature occurs at or *posterior* to the umbo. From the umbo forward, the shell is very gently curved, becoming straight near the anterior margin.

The primary costellae are strongly defined and coarse; the central one is the sharpest, the lateral ones growing gradually smaller until there is no differentiation of size on the posterolateral slopes. The number of smaller costellae between the primaries is highly variable among the specimens, and also between the median line and the cardinal angles on any one specimen. When there are five or more smaller costellae between two primaries, the central one of this group is larger than the others, but not so large as the primaries.

The concentric lines are strong, relatively coarse, and have a crenulated appearance due to crossing the radial costellae. Growth lines are usually not conspicuous, when present, and there are no diagonal wrinkles along the cardinal margin.

The pseudopunctae are easily visible on exfoliated specimens; they are spaced about 1 mm. apart and lie in regular rows between the costellae.

The brachial valve is nearly flat, and there is less differentiation of costellae, but the concentric growth lines are much stronger.

The interior of the pedicle valve shows a small fan-shaped muscle area, shallow and faintly defined, about one-fourth to one-third the length of the valve. The brachial interior is characterized by extreme simplicity. The two branches of the cardinal process are elongate and narrow, closely attached to the shell surface, and extend anteriorly almost parallel to each other, with the myophores at a low angle to the surface. The median ridge is low and rounded, extending anteriorly about one-third the length of the shell. The muscular impressions consist only of shallow depressions neither bounded nor divided by radial ridges. Beyond the muscle areas the inner surface of both valves is marked by radiating rows of pustules.

Hinge width of type specimen, 26.5 mm.; median length, 23 mm. Hinge width at the 15 mm. growth stage, 20 mm.; ratio of length to width, 1:1.33.

Discussion.—The Cincinnatian forms hitherto designated as *Rafinesquina "alternata"* do not conform to this definition; they are larger and much more convex, have the greatest convexity near the anterior margin, have less regular and finer costellae, and the interior structures are all much more strongly developed than are those of *R. trentonensis.* (See *R. ponderosa* (Hall), pl. 85, figs. 11–13, and text figure 5c).

Rafinesquina hermitagensis of Bassler cannot be differentiated from *R. trentonensis.* Plastotypes show that the convexity, outline of the shell, and character of the pseudopunctae are like those of typical Hull and Sherman Fall specimens of *R. trentonensis,* despite the fact that in the original description *R. hermitagensis* is said to be "rather strongly convex in the median region." (Pl. 85, figs. 7–10.)

Types.—Neotype: Am. Mus. 25298, low Trenton, probably Hull, Watertown, Jefferson County, New York. Neoparatype: Am. Mus. 697/2, same horizon and locality. Plesiotype: Brachial interior, Columbia Univ. 25881, from the Guttenberg (Rockland equivalent) at Milbrig, Illinois. Types of *R. hermitagensis* Bassler, U. S. Nat. Mus.; plastotypes, Columbia Univ. 25906; Hermitage (Sherman Fall equivalent), Central Basin of Tennessee.

Range.—*R. trentonensis* is most abundant in the Hull formation of the Trenton group (42 specimens); it occurs much less frequently in both the underlying Rockland (15 specimens) and the overlying Sherman Fall (7 specimens). It has not been found by the writer in either the Black River or the higher Trenton formations. It is found in similar abundance in New York, southeastern Ontario and the Upper Mississippi

Valley (19 specimens from the Decorah; 1 from the Prosser).

RAFINESQUINA ELONGATA Salmon, n. sp.
Plate 85, figures 14–17

Outline elongate U-shaped, with narrow, extended cardinal ears. Lateral margins nearly straight, converging slightly; anterior margin narrowly rounded. Length and width at hinge about equal, although the shell has the appearance of being longer than wide. The ratio of median length to hinge width at the 15 mm. growth stage is low.

Convexity low, sharpest curvature at the umbo, followed by a gradually lessening curvature anteriorly.

Costellae strongly differentiated in the central part of the shell, less so on the posterolateral slopes.

In the pedicle interior the muscle area is about equal in length and breadth; the posterior marginal ridges (dental lamellae) diverge at an angle of about 90°, and the anterior border is very vaguely marked but appears to curve gently toward the median line, where a blunt angle is formed. The greatest width of the muscle area is about two-thirds of its length from the beak. It occupies about one-third the length of the entire shell. The brachial interior is unknown.

Hinge width of the type specimen, 31 mm.; median length, 28 mm. Hinge width at the 15 mm. growth stage, 18 mm.; ratio of length to width, 1:1.2.

Discussion.—This species is essentially like *R. trentonensis* except that the outline of the shell is much more elongate, and the curvature over the umbo is somewhat sharper.

Types.—Holotype: Columbia Univ. 25883, Guttenberg (Rockland equivalent), Milbrig, Illinois. Paratype: Columbia Univ. 25882, same horizon and locality.

Range.—Known only from the Guttenberg of Illinois. Occurs with *R. trentonensis* but is rarer. Sixteen specimens.

RAFINESQUINA LENNOXENSIS Salmon, n. sp.
Plate 85, figures 18–20

Outline broadly U-shaped, with no cardinal ears. Greatest width 6–9 mm. anterior to hinge line. Lateral margins faintly sinuous near the cardinal angles, then broadly rounded. Anterolateral margin narrowly rounded.

Convexity moderate, broadly curved from the umbo forward, lessening toward the anterior but with no definite break in curvature. The radius of curvature is long, and the shells attain a large size.

Costellae regularly differentiated over the entire surface, with a rather narrow interval of secondary costellae between the primaries.

The ratio of length to width at the 15 mm. growth stage is high, ranging from 1:1.2 to 1:1.6.

The pedicle muscle area is nearly circular in outline, with rather strongly marked, crenulated posterior and lateral borders. The anterior border is regularly curved, but faintly delimited and not so strongly crenulate. The brachial interior is of the primitive type, with very short lateral ridges of adventitious shell material and a short, low median ridge, not more than one-fifth the length of the valve.

Hinge width of the type specimen, ±33 mm.; median length, 34 mm. Hinge width at the 15 mm. growth stage, 18 mm.; ratio of length to width, 1:1.2.

Discussion.—This large, broadly curved species is very characteristic of the upper Rockland in some localities in New York and Canada. The most nearly similar species are *R. olliformis*, n. sp., and *R. robusta* Wilson. The present species is distinguished from the former by its outline, which is broader in proportion to the length, and by the radius of curvature, which is longer than in *R. olliformis*, thus giving *R. lennoxensis* a relatively lower convexity and a larger size. *R. lennoxensis* is distinguished from *R. robusta* Wilson in that the latter is a much more convex and a much narrower form, although its size is large.

Types.—Holotype: Columbia Univ. 25884, Napanee member of the Rockland formation, Selby Creek, near Napanee, Lennox and Addington County, Ontario. Paratype: Columbia Univ. 25885, Rockland formation, Sugar River, Lewis County, near Booneville (Oneida County), New York.

Range.—Rockland of northwestern New York and southeastern Ontario. Common at a few localities. Twenty specimens.

RAFINESQUINA OLLIFORMIS Salmon, n. sp.
Plate 85, figures 21, 22

Outline pot-shaped; widest 9–12 mm. anterior to the beak. Small flat cardinal ears, lateral margins deeply sinuate anterior to the ears, then forming a semicircular curve with the anterior.

The convexity is moderate, with a rather narrow continuous curvature from the beak to the anterior.

The costellae are differentiated over the entire surface, but most strongly in the central area, with a small number of secondary costellae between the primaries. The costellae are all comparatively coarse. There is a tendency to develop occasional very strong growth lines.

The ratio of length to hinge width is low; the shell appears to be equidimensional, but is slightly wider than long. Interior unknown.

Hinge width of the type specimen, 27 mm.; median length, 22 mm. Hinge width at the 15 mm. growth stage, 18 mm.; ratio of length to width, 1:1.2.

Discussion.—*R. olliformis* has been differentiated from *R. lennoxensis* in the discussion of the latter species. It might be confused with *R. praecursor* Raymond, but the outline of the shell is different, since *R. praecursor* is narrowly ovate; the convexity is also different, since *R. praecursor* has a definite geniculation, while *R. olliformis* has none.

Types.—Holotype: Columbia Univ. 25886 Napanee member of the Rockland formation, Selby road 1 mile from Napanee, Lennox and Addington County, Ontario.

Range.—Found only at the type locality and horizon, where it is frequent. Twenty specimens.

RAFINESQUINA ROBUSTA Wilson
Plate 85, figures 23–25

Rafinesquina robusta WILSON, *1932*, Royal Soc. Canada Trans., ser. 3, vol. 26, sec. 4, p. 396, pl. 5, figs. 14–16.

Outline bluntly triangular in ventral view; lateral margins gently curved, anterior narrowly rounded. Convexity high, continuously curved from the umbo forward, the rate of curvature increasing gradually; outline of the profile nearly semicircular. Lateral margins also curved down very steeply. No definite geniculation is discernible. The shells attain a large size, averaging 35 mm. long by 35 mm. wide; greatest width at the hinge line. The ratio of length to width at the 15 mm. growth stage is extremely high, about 1:1.53 to 1:1.73.

The pedicle muscle area attains a length of nearly half that of the entire shell. It is broadly wedge-shaped, with the greatest width occurring almost at the anterior margin of the area. The posterior margins are marked by rather sharp ridges, which diverge at an angle of about 60°. The anterior margin is very gently curved, and the anterolateral angles bluntly rounded. The adductor track is broad and strongly marked, causing the anterior margin to be sinuate in the center. The brachial interior is unknown.

Discussion.—*R. robusta* differs from *R. deltoidea* and *R. camerata* in shape and size, and in having no definite geniculation. It differs from *R. lennoxensis* of the Rockland in having a much shorter radius of curvature, so that *R. lennoxensis* is relatively flatter, although it is equally large.

Types.—Holotype: National Museum of Canada, Ottawa, Ontario, No. 6655, upper Cobourg formation, east half of Lot 9, Con. IV, Roxborough Tp., Stormont County, Ontario. Paratype: No. 6655a, same locality and horizon.

Plesiotypes: Columbia Univ. 25526 and 25910, from the upper Cobourg at Copenhagen, Lewis County, New York.

Range.—Upper Cobourg (29 specimens) and Collingwood (6 specimens). Most abundant in the upper Cobourg at Copenhagen, New York, and in the Cornwall area of southeastern Ontario. Occurs sparingly in the Collingwood limestone at Craigleith, Ontario. Specimens of similar appearance, but slightly less convexity and lower ratio of length to width, are moderately common in the Prosser formation (Sherman Fall equivalent) of Iowa (7 specimens).

RAFINESQUINA MINUTA Salmon, n. sp.
Plate 85, figures 26, 27

Outline broadly triangular, rounded anteriorly. Widest at hinge line, cardinal angles nearly rectangular. The convexity is very high, extremely sharply rounded continu-

ously from the umbo forward. The radius of curvature is very short, so that the shell is exceedingly small. The length of most apparently mature specimens is about 11 mm. The ratio of length to width is only moderately high, ranging from 1:1.25 to 1:1.36.

The costellae are not differentiated, except that the central one is stronger than the others. In general, all the costellae are fine. Interior unknown.

Hinge width of type specimen, 15 mm.; median length, 12 mm. Ratio of length to width, 1:1.25.

Discussion.—This small species is distinguished from all others by its minute size and extremely sharp curvature. There are other rare specimens, somewhat larger but having the same shape, which may belong to this species.

Holotype.—Columbia Univ. 25887, low upper Cobourg, Point Petre, Athol Tp., Prince Edward County, Ontario.

Range.—Sherman Fall (1 specimen); lower Cobourg (4 specimens) and upper Cobourg (4 specimens). Northwestern New York and southeastern Ontario.

RAFINESQUINA PRESTONENSIS Salmon, n. sp.
Plate 85, figures 28–33

?Rafinesquina alternata (Conrad). WELLER, *1903*, New Jersey Geol. Survey, Palaeontology, vol. 3, p. 148, pl. 9, figs. 12, 13.

Outline broadly rounded, with very extended ears, which are flat, not bent down at the sides. The ears are broad, and the cardinal angles about 60°. Lateral margins strongly sinuate anterior to the ears, then forming a semicircle with the anterior margin

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EXPLANATION OF PLATE 85

All figures about ×1 unless otherwise indicated.

FIGS. *1–3*—*Rafinesquina trentonensis* (Conrad), neotype, Am. Mus. 25298. Pedicle valve, figured by Hall (1847, pl. 31, fig. 1a). *1*, Ventral view; *2*, lateral view, ×½±; *3*, anterior view, ×½±. (p. 574)

4, 5—*R. trentonensis* (Conrad), neoparatype, Am. Mus. 697/2. Pedicle valve, figured by Hall (1847, pl. 31A, fig. 1d). *4*, Ventral view; *5*, lateral view, ×½±. (p. 574)

6—*R. trentonensis* (Conrad), plesiotype, Columbia Univ. 25881. Brachial valve, interior. (p. 574)

7, 8—*R. "hermitagensis"* Bassler, plastotype, Columbia Univ. 25906. Cast of pedicle valve figured by Bassler (1932, pl. 12, fig. 5). *7*, Ventral view; *8*, lateral view. (=*R. trentonensis.*) (p. 574)

9, 10—*R. "hermitagensis"* Bassler, plastotype, Columbia Univ. 25906. Cast of pedicle valve figured by Bassler (1932, pl. 12, fig. 6). *9*, Ventral view; *10* lateral view. (=*R. trentonensis.*) (p. 574)

11–13—*R. ponderosa* (Hall), holotype, Am. Mus. 697/18 (Cincinnatian of Ohio), for comparison with *R. trentonensis. 11*, Pedicle valve, ventral view; *12*, brachial valve, dorsal view; *13*, pedicle valve, lateral view. ×⅔±. (p. 574)

14, 15—*R. elongata* Salmon, n. sp., holotype, Columbia Univ. 25883. Pedicle valve. *14*, Ventral view; *15*, lateral view. (p. 576)

16, 17—*R. elongata* Salmon, n. sp., paratype, Columbia Univ. 25882. Pedicle valve. *16*, Ventral view; *17*, lateral view. (p. 576)

18, 19—*R. lennoxensis* Salmon, n. sp., holotype, Columbia Univ. 25884. Pedicle valve. *18*, Ventral view; *19*, lateral view. (p. 576)

20—*R. lennoxensis* Salmon, n. sp., paratype, Columbia Univ. 25885. Brachial valve, interior. (p. 576)

21, 22—*R. olliformis* Salmon, n. sp., holotype, Columbia Univ. 25886. Pedicle valve. *21*, Ventral view; *22*, lateral view. ×⅔±. (p. 577)

23, 24—*R. robusta* Wilson, plesiotype, Columbia Univ. 25526. Pedicle valve. *23*, Ventral view; *24*, lateral view. (p. 577)

25—*R. robusta* Wilson, plesiotype, Columbia Univ. 25910. Internal mold of pedicle valve. (p. 577)

26, 27—*R. minuta* Salmon, n. sp., holotype, Columbia Univ. 25887. Pedicle valve. *26*, Ventral view; *27*, lateral view. (p. 578)

28, 29—*R. prestonensis* Salmon, n. sp., holotype, Columbia Univ. 25888. Pedicle valve. *28*, Ventral view; *29*, lateral view. (p. 578)

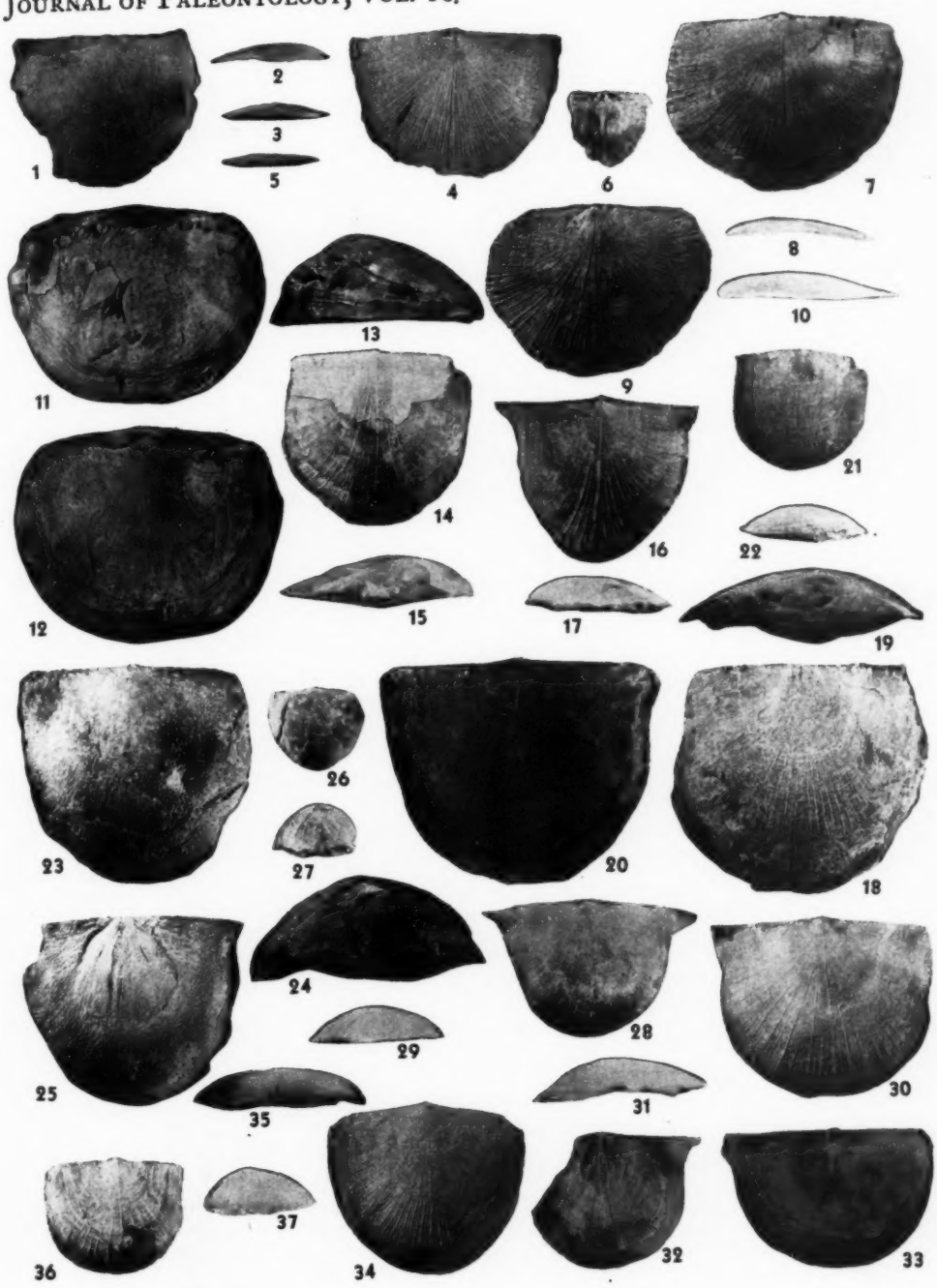
30, 31—*R. prestonensis* Salmon, n. sp., paratype, Columbia Univ. 25889. Pedicle valve. *30*, Ventral view; *31*, lateral view. (p. 578)

32—*R. prestonensis* Salmon, n. sp., paratype, Columbia Univ. 25890. Pedicle valve, interior. (p. 578)

33—*R. prestonensis* Salmon, n. sp., paratype, Columbia Univ. 25891. Brachial valve, interior. (p. 578)

34, 35—*R. lewisensis* Salmon, n. sp., holotype, Columbia Univ. 25892. Pedicle valve. *34*, Ventral view; *35*, lateral view. p. (579)

36, 37—*R. carlottina* Wilson?, plesiotype, Columbia Univ. 25893. Pedicle valve. *36*, Ventral view; *37*, lateral view. (p. 580)



Salmon, Mohawkian Rafinesquinae

The convexity is moderate, with the strongest curvature occurring about 9 mm. anterior to the beak, so that the highest portion of the shell is toward the anterior. The curvature of the shell is such that no definite angle between the posterior and anterior sections can be measured.

The proportion of length to width is relatively high, varying between 1:1.20 and 1:1.6. The costellae are sharply differentiated over the entire surface, but the largest primaries occur in the central portion of the anterior. The intervals of secondaries are high, four to five between each two primaries in most cases.

The muscle area of the pedicle valve is elongate and rhomboid in shape, with a narrowly angular anterior margin. It reaches about half the median length of the valve. The brachial interior is of the primitive type.

Hinge width of holotype, 30.5 mm.; median length, 20 mm. Hinge width at the 15 mm. growth stage, 21 mm.; ratio of length to width, 1:1.4.

Hinge width of Sherman Fall paratype, 33 mm.; median length, 25.5 mm. Hinge width at the 15 mm. growth stage, 21 mm.; ratio of length to width, 1:1.4.

Discussion.—There is a slight variational difference between the Hull and Sherman Fall specimens of this species, in that the former are longer and narrower, while the latter are shorter and broader. The Sherman Fall specimens also attain a larger size; their greatest convexity occurs about 15 mm. from the beak, as compared with an average of 9 mm. in the Hull type. However, infrequent specimens of each type occur with the other type, and since they are so nearly alike, it is believed that the differences between them may be of an environmental nature, and that they probably all belong to the same species.

R. prestonensis differs from *R. trentonensis* in being more strongly convex and in having the position of the greatest convexity considerably anterior to, rather than at or posterior to, the umbo. *R. trentonensis* does not develop such extended ears.

Types.—Holotype: Columbia Univ. 25888, from the Hull formation at Preston Cove, Amherst Island, Lennox and Addington County, Ontario. Paratypes: Columbia Univ. 25889, from the Shoreham member of the Sherman Fall formation, between 5 feet and 46 feet in the section along Stony Creek, Middleville, Herkimer County, New York; Columbia Univ. 25890 and 25891, from the middle Hull, along the shore road between Sandhurst and Bath, Ernestown Tp., Lennox and Addington County, Ontario.

Range.—Rockland to Sherman Fall. Rare in the Rockland (4 specimens); abundant in the Hull (32 specimens) and Sherman Fall (13 specimens). Occurs in the Guttenberg (Rockland equivalent) at Milbrig, Illinois (8 specimens); in the Hull at Belleville, Ontario, and at Preston Cove and along the shore road opposite Amherst Island, between Sandhurst and Bath, Ontario; also at Sacket Harbor, Jefferson County, and Denmark, Lewis County, New York. It is found in the Sherman Fall at Middleville, and along Deer River in Lewis County, New York; at Prinyer Cove, Cressy Tp., Prince Edward County, Ontario.

RAFINESQUINA LEWISENSIS Salmon, n. sp.
Plate 85, figures 34, 35

Outline broadly U-shaped; greatest width at the hinge line; cardinal angles blunt, without ears, forming an angle of about 90°. Lateral margins nearly straight, converging slightly; anterior margin broadly rounded.

Convexity low, posterior flattened, geniculation narrowly rounded, not angular, occurring about 18–20 mm. from the beak. Angle between the posterior portion and the anterior slope, about 160°.

Costellae all very coarse, with no differentiation. Ratio of length to width high, varying from 1:1.26 to 1:1.67. Interior unknown.

Hinge width of type specimen, 30 mm.; median length, 24 mm. Hinge width at the 15 mm. growth stage, 20 mm.; ratio of length to width, 1:1.33.

Discussion.—*R. lewisensis* resembles *R. edmondensis* and *R. normalis*. It differs from the first in having a wider angle between the posterior and anterior portions of the shell, and in having coarser, undifferentiated costellae. It differs from the second in that *R. normalis* has a triangular outline and a steeper angle between the posterior and anterior portions of the shell.

Holotype.—Columbia Univ. 25892, Den-

mark member of the Sherman Fall formation, Mill Creek, Lowville, Lewis County, New York.

Range.—Sherman Fall (7 specimens); lower Cobourg (2 specimens) and upper Cobourg (1 specimen). Occurs in the Sherman Fall at Prinyer Cove, Cressy Tp., Prince Edward County, Ontario; Mill Creek, Lowville, New York, and at Lakeville, Peterborough County, Ontario. Occurs in the lower Cobourg (or high Sherman Fall?) at Cape Versey, North Marysburgh Tp., Prince Edward County, Ontario, and in the upper Cobourg at Point Petre, Athol Tp., Prince Edward County, Ontario.

RAFINESQUINA WINCHESTERENSIS Foerste

Rafinesquina winchesterensis FOERSTE, *1910*, Denison Univ., Sci. Lab., Bull. 16, p. 42, pl. 5, figs. 13a–c.

Outline elongate U-shaped, lateral margins nearly parallel, anterior evenly rounded. Length and width nearly equal. Posterior section of the shell gently rounded in lateral view, the geniculation narrowly rounded, not angular, usually about 160°, and occurring at 20–25 mm. from the beak.

The muscle area of the pedicle valve is described by Foerste as indistinctly defined anteriorly, and the brachial interior is said to present the same features as most forms of *Rafinesquina* from the overlying Cincinnatian rocks. No interiors have been seen by the writer.

Discussion.—*R. winchesterensis* differs from *R. lewisensis* in having a more convex posterior portion, in being longer in proportion to width, and in having very fine costellae, differentiated to some extent in size.

Holotype.—Not seen. Depository unknown. Horizon, Greendale division of the Cynthiana formation (Collingwood equivalent). Locality, East of the Cincinnati geanticline, between Nicholas and Madison Counties in Kentucky.

Range.—Cynthiana of Cincinnati region (25 specimens). Not found in New York or Ontario.

RAFINESQUINA WINCHESTERENSIS Foerste var. FILISTRIATA Foerste

Rafinesquina winchesterensis filistriata FOERSTE, *1910*, Denison Univ., Sci. Lab., Bull. 16, p. 43, pl. 5, figs. 14, 15a–b.

Differs from the typical form of the species in being wider in proportion to length, so that the outline is broadly U-shaped. The convexity is also somewhat less; although the geniculation is situated in about the same position as that of the typical form, its angle is wider.

The costellae are said to be noticeably finer than those of the typical form, although among a large collection of topotypes of both forms, there appeared to the writer to be all gradations of size and amount of differentiation.

Discussion.—This variety, as well as the typical form, differs from *R. lewisensis*, which it most resembles, in being less flattened on the posterior portion and in having finer costellae.

Holotype.—Not seen. Depository unknown. Horizon and locality same as those of *R. winchesterensis*.

Range.—Same as that of *R. winchesterensis*.

RAFINESQUINA CARLOTTINA Wilson?
Plate 85, figures 36, 37

Rafinesquina carlottina WILSON, *1932*, Royal Soc. Canada Trans., ser. 3, vol. 26, sec. 4, p. 395, pl. 5, figs. 3, 4.

The outline and convexity of this species are difficult to ascertain from the original description and illustrations, the single specimen being apparently incomplete, and not being shown in side view. No topotype material was obtained, so that it is impossible for the writer to identify specimens with this form with certainty.

However, there is a small group of specimens in the writer's collections which have been tentatively identified as *R. carlottina*. The outline is shield-shaped or pentagonal, with blunt angles. The cardinal angles are about 90°; the lateral margins nearly straight, with blunt anterolateral angles separating them from the narrowly rounded anterior margin.

The convexity is moderately high, with a rounded, not angular, geniculation about 12 mm. from the beak; the angle between the posterior and anterior portions is about 120°. The lateral margins have a lower slope and no geniculation with the median section.

The ratio of length to width is very great;

in some specimens it is as high as 1:1.6. Interior not seen.

Types.—Holotype: National Museum of Canada, Ottawa, Ontario, No. 6652, lower Cobourg formation, east half of Lot 35, Con. IX, Charlottenburg Tp., Glengarry County, Ontario (outcrop not found October, 1936). Plesiotype: Columbia Univ. 25893, from the lower Cobourg formation along the north branch of Moose Creek, Lewis County, northwest of Booneville (Oneida County), New York.

Range.—Hull? (1 specimen); Sherman Fall (12 specimens), and lower Cobourg (2 specimens). Tentatively identified specimens were found in the upper Sherman Fall along Mill Creek at Lowville, Lewis County, New York; in the lower Cobourg along the north branch of Moose Creek near Booneville, and at Cape Versey, North Marysburgh Tp., Prince Edward County, Ontario; in the Hull one doubtful specimen was found east of Mt. Pleasant Church, west of Napanee, in Richmond Tp., Lennox and Addington County, Ontario.

RAFINESQUINA DEERENSIS Salmon, n. sp.
Plate 86, figures 1, 2

Outline broadly pentagonal or shield-shaped, with very small, slightly projecting, acute cardinal ears. The lateral margins are faintly sinuate below the ears, then nearly parallel for about 5 mm. Anterolateral angles about 120°. Anterior margin somewhat nasute in the center.

Convexity moderate to high; posterior portion flattened, anterior slope nearly straight, making an angle of 90° to 120° with the posterior. Geniculation sharply angular, occurring about 15 mm. from the beak. The lateral margins, including the margins of the ears, are even more sharply geniculate than the anterior.

Costellae in general fine, alternating strongly in the central area of the shell, the alternation dying out on the posterolateral slopes. The interval of secondary costellae between the primaries is usually small in the median region, about 2 to 4, growing wider on the sides.

The ratio of length to width is high, ranging from 1:1.33 to 1:1.6.

The muscle area in the pedicle valve is elongate to broadly oval, extending one-third to one-half the length of the valve. It is very vaguely delimited and marked with fine radial ridges. The adductor track is narrow. The brachial interior is that of the complex type (text fig. 5b); the lateral ridges are continued anteriorly as fine lines running parallel with the median ridge, which also is long and very narrow on the anterior.

Hinge width of the type specimen, 23 mm.; median length, 19 mm. Hinge width at the 15 mm. growth stage, 20 mm.; ratio of length to width, 1:1.33.

Discussion.—*Rafinesquina carlottina?* has the same subpentagonal outline as the present species, but the profile in lateral view is quite different, since *R. carlottina?* always has the bluntly angular geniculation sloping at an angle of 120° or more and occurring nearer the beak, giving the shell the appearance of having the highest portion in the posterior half of the shell, whereas *R. deerensis* has a sharply angular geniculation, usually nearly 90°, situated at a greater distance from the beak, so that the highest part of the shell appears to be at the front. The lateral margins in this species are also sharply geniculate, whereas those of *R. carlottina?* are gently curved in the anterior portion and flatten out, with no geniculation whatever, at the cardinal angles.

Holotype.—Columbia Univ. 25894, upper Cobourg, 20 feet above the base, bluff along Deer River above the dam at Copenhagen, Lewis County, New York.

Range.—Lower Cobourg (18 specimens, some doubtful) and upper Cobourg (58 specimens), northwestern New York and southeastern Ontario. The lower Cobourg specimens attain a smaller size when mature, and the anterior margin apparently does not continue to grow so far after the geniculation, so that the shell does not appear to be so high as those of the upper Cobourg specimens.

RAFINESQUINA DECLIVIS (James)
Plate 86, figures 3–13

Strophomena declivis JAMES, *1874*, Cincinnati Quart. Jour. Sci., vol. 1, p. 240.
Rafinesquina declivis, FOERSTE, *1910*, Denison Univ., Sci. Lab., Bull. 16, p. 43, pl. 2, fig. 4; pl. 5, figs. 12a–d.

Foerste (1910) considered that the shape

of the specimen first described by James was due to compression during fossilization, and the writer fully concurs in this opinion. From the appearance of the other specimens in the series of syntypes, it seems that the normal outline is that of the specimen figured as 12d in Foerste's paper (see pl. 86, figs. 6–8). The definition of the species should probably be as follows:

Outline broadly U-shaped, rectangular or narrowly U-shaped. Lateral margins gently curved, converging more or less rapidly; anterior broadly to narrowly rounded.

Convexity moderate; posterior portion low, anterior slope nearly straight, forming a bluntly angular geniculation about 14 mm. from the beak, at an angle of about 120° with the posterior portion.

The ratio of width to length is moderate to high, ranging from 1:1.265 to 1:1.53 (in the shortest and broadest specimen). Median costella always prominent, with definite and sharp differentiation of costellae on the anterolateral slopes, continuing around to the cardinal angles. The costellae in general are coarse.

The pedicle interior was not seen. The brachial interior (a topotype, in the same hand specimen as one of the syntypes) is rather primitive; the median ridge is stout and short, extending about one-fourth the length of the valve; posterior margins of the adductor scars marked by wide, low ridges of adventitious material, which disappear anteriorly after a short distance. There are no lateral ridges. The entire inner surface is covered by rows of very sharp and prominent pustules, even within the muscle areas. They are especially strong on the posterolateral slopes of the posterior ridges.

Types.—Syntypes: University of Chicago, Walker Museum 2392 (4 pedicle valves), Cynthiana formation, near Boyd's Station, on the Kentucky Central, about 30 miles south of Cincinnati, Ohio. Foerste illustrated a syntype, pl. 5, fig. 12c, which was not found by the writer among the University of Chicago specimens. The fourth syntype in the collection, not illustrated here, is the external impression of a brachial valve. Topotype: Univ. Chicago, Walker Museum, same number (brachial interior); same horizon and locality.

Range.—Cynthiana formation of the Cincinnati region (5 specimens). Not found in New York or Ontario.

RAFINESQUINA PRAECURSOR Raymond
Plate 86, figures 14, 15

Strophomena alternata (Conrad). BILLINGS, *1863*, Canada Geol. Survey Rept. Prog. to 1863, p. 163, fig. 140.
Strophomena alternata (Conrad). CHAPMAN, *1862*, Canadian Jour. Industry, Sci. and Art, vol. 7, p. 112, fig. 95.
Strophomena alternata (Conrad). CHAPMAN, *1863*, *idem*, vol. 8, p. 199, fig. 186.
Strophomena alternata (Conrad). CHAPMAN, *1864*, A popular and practical exposition of the minerals and geology of Canada, figs. 95, 186 (reprint).
Rafinesquina praecursor RAYMOND, *1921*, Canada Geol. Survey Mus. Bull. 31, p. 22, pl. 7, fig. 5.
??Rafinesquina (*Kjaerina*) *praecursor*, REED, *1936*, Palaeontologia Indica, n. ser., vol. 21, pt. 3, p. 71, pl. 3, fig. 18.

Outline narrowly ovate, widest at or near the hinge line, with small or no ears; cardinal angles about 90°. Lateral margins not sinuate, gently curved; anterior margin narrowly rounded.

Convexity moderate; posterior portion gently rounded; geniculation rounded, not angular, about 18 mm. from the beak, and forming an angle of about 120°. Lateral margins also curved down steeply, including the margins of the cardinal ears when present.

Ratio of length to width moderate, ranging from 1:1.23 to 1:1.53, but with most specimens nearer 1:1.23. Costellae in general coarse, alternating in size irregularly and at small intervals around the entire shell.

The pedicle muscle area is ovate, marked by a fine ridge around the posterior and posterolateral margins, the ridge becoming much less distinct on the anterior. The widest portion of the area is near the posterior, about one-third the length of the area from the beak. The entire muscle area extends to about one-half the length of the shell. The anterior margin of the scar is rather sharply angular, but the lateral margins are evenly rounded. The adductor track is represented by a fine ridge along the median line.

Discussion.—Raymond referred "*Leptaena alternata*" Hall, 1847, Pal. N. Y., vol. 1, pl. 31A, figs. 1f–h, to this species. Fig. 1f

resembles Raymond's figure of the type specimen of *R. praecursor*, but the other two figures show a sharp fold along the median line of the specimens, thus resembling *R. nasuta* of the Lorraine group (Cincinnatian) or crushed and unidentifiable specimens of some species of *Rafinesquina*.

R. (*Kjaerina*) *praecursor* Reed probably does not belong in the synonymy of this species, since the figures of the Indian specimens do not resemble the American form of *R. praecursor*.

The species most nearly related to *R. praecursor* are, on the one hand, *R. prestonensis*, and on the other, *R. deltoidea*. *R. praecursor* differs from the first in having the area of greatest curvature nearer the anterior and much more definite and angular; *R. prestonensis* also tends to have strongly developed flat ears, whereas *R. praecursor* either has no ears or has very small ones, which are always bent down along the margins. *R. praecursor* differs from *R. deltoidea* in outline, being ovate rather than "deltoid" (actually pentagonal, not triangular); *R. deltoidea* also has a much more sharply angular geniculation (the angle, however, being about the same in both species), while that of *R. praecursor* is narrowly rounded.

Types.—Holotype: National Museum of Canada, Ottawa, Ontario, upper Sherman Fall formation, Trenton, Ontario. Topotype: Columbia Univ. 25895, from the Sherman Fall near Lock 2, on Trent River, about 1 mile above Trenton, Ontario.

Range.—Rockland(?) (1 specimen); Sherman Fall (32 specimens) and lower Cobourg (7 specimens); northeastern New York and southeastern Ontario. The single Rockland specimen differs from the typical Sherman Fall form in being narrower and longer, and in having small ears, which are flat. It has been distorted on the anterior margin, producing a nasute appearance, and perhaps it may be *R. prestonensis* rather than this species.

The lower Cobourg specimens, which are much rarer than those of the Sherman Fall, are somewhat broader in proportion to length than the Sherman Fall type and seem to be a slightly smaller shell at maturity; nevertheless they are most like *R. praecursor*.

RAFINESQUINA DELTOIDEA (Conrad), emended

Plate 86, figures 16–20

Leptaena deltoidea CONRAD, *1838*, New York Geol. Survey Second Ann. Rept., p. 115 (nomen nudum).

Strophomena deltoidea CONRAD, *1839*, *idem*, Third Ann. Rept., p. 64.

Strophomena deltoidea, CONRAD, *1841*, *idem*, Fifth Ann. Rept., p. 37 (list).

Strophomena deltoidea, EMMONS, *1842*, Geology of New York, pt. 2, p. 389, fig. 2 (no description).

Strophomena deltoidea, VANUXEM, *1842*, *idem*, pt. 3, p. 46, fig. 2 (after Emmons).

Strophomena deltoidea, MATHER, *1843*, *idem*, pt. 1, p. 397, fig. 2 (after Emmons).

Strophomena deltoidea, OWEN, *1844*, Am. Jour. Sci., ser. 1, vol. 47, p. 363, fig. 2 (after Emmons).

Leptaena deltoidea, HALL, *1847*, Palaeontology of New York, vol. 1, p. 106, pl. 31A, figs. 3a–f (3f = holotype).

Strophomena deltoidea, EMMONS, *1855*, American geology, vol. 1, pt. 2, p. 197, pl. 11, figs. 5a, c(?) (not listed in the plate explanation).

Strophomena deltoidea, BILLINGS, *1863*, Canada Geol. Survey Rept. Prog. to 1863, p. 163, fig. 141.

Streptorhynchus (*Strophonella*) *deltoidea*, HALL, *1883*, New York State Geologist Second Ann. Rept., pl. 42(9A), figs. 1–2(?), 4 (not figs. 3, 5–7, nor pl. 39(9), figs. 10–14, which are all *Strophomena*) (fig. 4 = holotype).

Strophomena deltoidea, LESLEY, *1890*, Pennsylvania Second Geol. Survey Rept. P4, p. 1125, figs. in part (only the figures copied from Emmons, 1842, and from Billings; not the figure copied from Owen, 1852).

Rafinesquina deltoidea, HALL and CLARKE, *1892*, New York Geol. Survey, Palaeontology, vol. 8, pt. 1, pl. 9A, figs. 1–2(?), 4 (after Hall, 1883).

?Rafinesquina deltoidea, WHITEAVES, *1897*, Canada Geol. Survey, Palaeozoic Fossils, vol. 3, pt. 3, p. 170.

?Rafinesquina deltoidea, GRABAU and SHIMER, *1909*, North American index fossils, vol. 1, p. 212.

Rafinesquina deltoidea, KAY, *1937*, Geol. Soc. America Bull. 48, p. 301, pl. 10, figs.

Not *Strophomena deltoidea* Conrad. OWEN, *1844*, Report of a geological exploration of part of Iowa, Wisconsin, and Illinois . . . in 1839, pl. 16, fig. 8; pl. 17, fig. 6.

Not *Leptaena deltoidea* (Conrad). OWEN, *1852*, Report of a geological survey of Wisconsin, Iowa, and Minnesota, p. 629, tab. 2B, fig. 10.

Not *Strophomena deltoidea* Conrad. DAVIDSON, *1871*, A monograph of the British fossil Brachiopoda, vol. 3, Devonian and Silurian species, p. 292, pl. 42, figs. 1–5; pl. 39, fig. 22 (*Opikina* sp.).

Not *Strophomena deltoidea* Conrad. DAVIDSON, *1883*, *idem*, vol. 5, Silurian supplement, p. 197, pl. 15, figs. 16–32 (*Opikina* sp).

Not *Rafinesquina deltoidea* (Conrad). WINCHELL and SCHUCHERT, *1893*, Minnesota Geol. and

Nat. History Survey Final Rept., vol. 3, pt. 1, p. 403, pl. 31, figs. 30, 31.

Not *Playfairea deltoidea* (Conrad). REED, *1917*, Royal Soc. Edinburgh Trans., vol. 51, p. 866, pl. 11, figs. 21–30.

The holotype of this species is the external impression of a brachial valve. The original description, and the most extensive later description of it, that of Hall in 1847, seem not to have taken this fact into account; the idea of the species which has been most common among later authors is that the shell is extremely flat in the posterior portion.

Whole specimens show that this idea is erroneous, and that the posterior part of the pedicle valve is moderately to strongly convex. The emended description is drawn from specimens collected at the type locality, Trenton Falls, which have an outline similar to that of the holotype.

Emended description.—Outline broadly triangular to subpentagonal, with small cardinal ears, which are abruptly bent down on the sides. Lateral margins faintly sinuate below the ears, then nearly straight or gently curved, converging rapidly. Anterior margin strongly angular in the center. There is frequently a well-defined anterolateral angle.

Convexity high; posterior portion gently to strongly rounded, anterior portion nearly straight; geniculation angular, sharply marked, about 18 mm. from the beak, forming an angle of 90° to 120°.

The costellae are not particularly coarse, differentiated in size in the median region, but not prominently. Concentric wrinkles may or may not be present on the posterior portion of the shell; they are much less prominent and constant than on the brachial valve; the fact that the holotype is a brachial valve has given rise to an erroneous impression with regard to this character as well as to the convexity.

In the pedicle valve the muscle area is relatively elongate and narrow; it is bordered by a strong crenulated ridge to the anterior end; the anterior is apparently open and unbordered, due to the comparatively great width of the adductor track. In some specimens the greatest width of the pedicle muscle area is at the posterior end, immediately anterior to the delthyrial cavity; in others it is one or two millimeters farther anterior. The lateral margins of the area converge very gradually, giving the scar its elongate, narrow character. In some specimens the lateral margins of the muscle area are more strongly curved, and the width of the area is therefore greater, so that the shape of the scar is ovate, as in *R. praecursor*.

The brachial interior is of the primitive type, with a small, low median ridge extending about one-fourth or one-third the length of the shell, and two broad, low curving ridges along the posterior edge, diverging at an angle of about 90°. The interior surface is marked by rows of strong pustules and also by the characteristic concentric wrinkles that mark the brachial exterior. There are no lateral ridges in the brachial muscle area.

R. deltoidea differs from *R. praecursor* in its outline, which is much more triangular and has a sharper anterior angle, and in the character of the geniculation, which is rounded, not angular, in *R. praecursor*.

Several local variations of this species have been observed; they differ in size and, to a slight extent, in shape. The Trenton Falls form, of which the holotype is one, is a rather large shell, being about 25 mm. wide and 20 mm. long on the average. The lower Cobourg forms from Ontario are somewhat smaller and relatively longer, having average dimensions of 20 mm. wide and 15 mm. long. The form from the Prosser of Iowa is smaller yet, averaging about 16 mm. wide and 12 mm. long. However, the outline and relative position and angle of the geniculation seem to be essentially alike in all these types, and they appear to have no more than a geographical significance.

Types.—Holotype: American Museum of Natural History, New York, No. 701/1, uppermost Sherman Fall or lower Cobourg. In the original description, Conrad gave the locality as Trenton Falls, New York. A note glued on the holotype reads: "The original of Mr. Conrad's species. Locality Middleville. J. Hall." However, no specimens resembling *R. deltoidea* have been found at Middleville, and the section there does not include beds within the known range of the species; it is therefore concluded

that the original locality was Trenton Falls, as stated by Conrad. Topotypes: Pedicle exterior, Columbia Univ. 25896; pedicle interior, no. 25897; brachial interior, no. 25898, from the uppermost Sherman Fall or lower Cobourg, from the top of the bluff above West Canada Creek, about three-quarters of a mile upstream from the Power House at Trenton Falls, Oneida County, New York.

Range.—Sherman Fall to upper Cobourg. Rare in the Sherman Fall, three doubtful specimens only having been found, along Mill Creek near Lowville, Lewis County, New York. It is very common, however, in the lower part of the Prosser formation, of about Sherman Fall age, near Elkader and Decorah, Iowa (16 specimens). It is most abundant in, and characteristic of, the lower Cobourg (85 specimens), in which it occurs throughout Prince Edward County, Ontario, and in northwestern New York. It is again very rare in the upper Cobourg, having been found in only one locality in Ontario (2 specimens).

RAFINESQUINA NORMALIS Wilson
Plate 86, figures 21–24

Rafinesquina normalis WILSON, *1932*, Royal Soc. Canada Trans., ser. 3, vol. 26, sec. 4, p. 395, pl. 5, figs. 5–7.

Outline broadly triangular, somewhat like that of *R. deltoidea*, but with the anterior margin narrowly rounded instead of angular. Cardinal extremities forming an angle of about 90°, sides nearly parallel at first, then rapidly converging. Convexity moderate; geniculation rounded, not angular, forming an angle of about 120°, and occurring at about 18 mm. from the beak. Sides of the shell much less steeply sloping than the anterior. The extent of the shell is quite short beyond the geniculation.

Costellae differentiated rather strongly in the central part of the shell. There are frequently prominent wrinkles on the posterolateral areas.

The ratio of length to width is high, ranging from 1:1.40 to 1:1.53. The larger and flatter specimens occur in the Cobourg; the smaller and higher in the Sherman Fall.

Discussion.—*R. normalis* differs from *R. praecursor* in outline: the latter is ovate, and the shell narrow, whereas *R. normalis* is broadly triangular. It differs from *R. deltoidea* in outline, being less angular, and in having the geniculation rounded instead of sharply angular. Although the costellae are strongly differentiated, this species differs considerably from *R. trentonensis* in outline and convexity.

Types.—Holotype: National Museum of Canada, Ottawa, Ontario; No. 6653, upper Cobourg, Lot C, Con. IX. Cornwall Tp., Stormont County, Ontario. Paratypes: No. 6654, same horizon and locality. Ideotypes (figured): Columbia Univ. 25899, from the Cobourg, Lot 1, Con. VIII, Cornwall Tp., Stormont County, Ontario, and no. 25900, from the upper Cobourg (20 feet), Copenhagen, Lewis County, New York.

Range.—Top Sherman Fall (1 specimen); lower Cobourg (9 specimens) and upper Cobourg (9 specimens). Northwestern New York and southeastern Ontario.

RAFINESQUINA EDMONDENSIS Salmon, n. sp.
Plate 86, figures 25, 26

Outline broadly U-shaped, widest at the hinge line. Cardinal angles extended in small, acute ears. Lateral margins gently rounded, anterior margin broadly and evenly rounded; no anterolateral angles.

Convexity moderate; posterior portion of the shell gently rounded, anterior nearly a straight slope. No definite geniculation, but the shell is most strongly curved about 20 mm. from the beak. The angle between the anterior slope and the posterior portion of the shell is about 120°. The area of shell beyond the sharpest curvature is small, so that the convexity of the shell as a whole does not appear to be great. The interior is unknown.

The costellae are fine in general, and differentiated over the entire shell. The interval of secondary costellae between the primaries is small.

The ratio of length to width is very high, 1:1.465 or more.

Hinge width of the type specimen, 36+ mm.; median length, 22 mm. Hinge width at the 15 mm. growth stage, 24 mm., ratio of length to width, 1:1.6.

Discussion.—This species most closely resembles *R. lewisensis* but differs from it in having the anterior portion more abruptly curved down: the angle of geniculation of

R. lewisensis is about 160°. It also differs in having fine but differentiated costellae, whereas *R. lewisensis* has very coarse and undifferentiated costellae.

Holotype.—Columbia Univ. 25901, cast and mold of pedicle exterior, Sherman Fall formation, Edmonde, east of Lake Clear, Renfrew County, Ontario.

Range.—Sherman Fall of southeastern Ontario. Forty specimens.

RAFINESQUINA EQUIPUNCTATA Wilson
Plate 86, figures 27–28

Rafinesquina equipunctata WILSON, *1932*, Royal Soc. Canada Trans., ser. 3, vol. 26, sec. 4, p. 394, pl. 5, figs. 1, 2.

Several specimens in the writer's collection have been identified with *R. equipunctata*, and the identifications of a few have been verified by Dr. Wilson. Since the original material of the species is said to have been rare and rather poorly preserved, it is believed that additional description based upon this new material will clarify the definition of this species.

Outline ovate, broad, varying toward rectangular. The greatest width in most specimens is at the hinge line. The cardinal angles are produced as small flat ears, which are not bent down at the sides. The anterior margin tends to be somewhat irregular.

The convexity is moderate; the posterior portion is gently curved, the anterior nearly straight. The geniculation is about 25 mm. from the beak, sharply curved but not angular. The angle between the posterior and anterior portions is about 120°.

The pedicle muscle area is fan-shaped, very nearly circular; it is bordered by a faint crenulate ridge, which becomes fainter toward the anterior. The adductor track is marked by a fine ridge along the median line. The entire muscle area is covered with fine striations, which run into the radial rows of pustules outside the area.

The brachial muscle scars are intermediate in development between the primitive and the complex (*b*) type; the median ridge and the posterior ridges are strong but narrow; the posterior ridges diverge at an angle of about 30° and curve anteriorly, so as to run nearly parallel. They are about 5 mm. long, while the median ridge is nearly 10 mm. long. There are also two stout, short lateral ridges arising within the muscle area near its anterior border; they extend beyond the ends of the posterior ridges only a short distance. The entire interior surface outside of the muscle area is covered with rows of very fine pustules.

Discussion.—*R. equipunctata* differs from *R. lewisensis* in having a sharper angle of geniculation, occurring at a greater distance from the beak; it differs from *R. edmondensis* in having coarser costellae, which are not differentiated, and in having the geniculation farther from the beak.

The distribution of the pseudopunctae cannot be relied upon as a specific character, since they may be spaced rather closely in some specimens of *R. equipunctata*, and also attain a relatively large size in some other species.

The ratio of length to width is usually rather high, ranging around 1:1.465 at the 15 mm. growth stage.

Types.—Holotype: National Museum of Canada, Ottawa, Ontario, No. 6637, lower Cobourg, east half of Lot 35, Con. IX, Charlottenburg Tp., Glengarry County, Ontario. Ideotype (figured): Columbia Univ. 25902, high Sherman Fall or lower Cobourg, Cape Versey, N. Marysburgh Tp., Prince Edward County, Ontario.

Range.—Rockland (?), Sherman Fall (1 specimen); lower Cobourg (14 specimens), and upper Cobourg (no specimens seen by the writer). Occurs in the Sherman Fall along Mill Creek, Lowville, Lewis County, New York; in the uppermost Sherman Fall or lower Cobourg at Cape Versey, North Marysburgh Tp., Prince Edward County, Ontario, and in the upper Cobourg in Roxborough Tp., Stormont County, Ontario. One specimen found in the Rockland along Sugar River, near Port Leyden, Lewis County, New York, resembles the other specimens of this species very strongly, yet is a larger shell, and may be an aberrant specimen of *R. lennoxensis* that has developed a definite geniculation instead of the continuous curvature typical of that species.

RAFINESQUINA CAMERATA (Conrad)
Plate 86, figures 29–34

Strophomena camerata CONRAD, *1842*, Acad. Nat. Sci. Philadelphia Jour., vol. 8, p. 254, pl. 14, fig. 5.

Leptaena camerata, HALL, *1847*, Palaeontology of New York, vol. 1, p. 106, pl. 31A, figs. 2a–b (holotype refigured).
Strophomena camerata, EMMONS, *1855*, American geology, vol. 1, pt. 2, p. 197.
Strophomena alternata Conrad. EMMONS (part), *1855*, *idem*, pl. 11, fig. 3 (upper), 5b(?), 1b(?).
Rafinesquina camerata, HALL and CLARKE, *1892*, New York Geol. Survey, Palaeontology, vol. 8, pt. 1, p. 283 (not described).
Rafinesquina deltoidea (Conrad). WINCHELL and SCHUCHERT (part), *1893*, Minnesota Geol. and Nat. History Survey Final Rept., vol. 3, pt. 1, p. 403, pl. 31, figs. 30, 31(?).
Rafinesquina camerata (part), RAYMOND, *1921*, Canada Geol. Survey Mus. Bull. 31, p. 21 (not the figures).
Not *Rafinesquina camerata* (Conrad). KAY, *1935*, Jour. Geology, vol. 43, pp. 578, 582 (listed only).

Most authors have considered this species synonymous with, or at most a variety of, *R. deltoidea*, basing their conclusions upon Hall's remarks, in 1847, that he was induced to believe so because of the presence of obscure wrinkles near the hinge line on *R. camerata*. The wrinkles may be disregarded as a specific character, since several other species possess them to varying degrees; nevertheless *R. camerata* differs from *R. deltoidea* in many other characters, as Raymond observed in 1921.

However, it appears that several different forms of highly gibbous Rafinesquinae have been grouped together under this name in the past, and it is now proposed to redescribe the holotype before discussing the species as a whole.

Ventral aspect bluntly triangular, wider than long. Greatest width at the hinge line; cardinal angles extended, very sharply angular, about 30°. Lateral margins sinuate anterior to the ears, then sharply converging, narrowly rounded. Anterior narrowly rounded. There is no anterolateral angle.

Convexity extremely high. Shell very gently curved from the umbo forward for about 12.5 to 13 mm., then very abruptly curved, then again gently curved, so that when the posterior portion is held horizontally, the anterior margin lies directly beneath the beak. The angle between the posterior and anterior portions of the shell is therefore less than 90°.

The holotype is exfoliated except for a small patch of shell over the umbo, so that the character of the costellae cannot be seen. The pseudopunctae are quite large and very far apart, in irregular rows. The dimensions of the valve must be estimated, since one cardinal ear is broken off: median length, 20 mm.; hinge width, about 28 mm. At the 15 mm. growth stage, the hinge width is about 22 mm.; ratio of length to width, 1:1.465.

The interior characters are described from specimens that appear to be conspecific with the holotype, although not found in the same area. The pedicle muscle area is like that of *R. sardesoni*, but proportionately smaller. It extends to the point where the geniculation of the shell begins. The borders of the area are very vaguely marked except for the posterior portion. Internal molds of this species and other highly convex upper Trenton forms show anastomosing ridges over the entire surface, which blend at the borders of the muscle areas into the radial ridges that mark the latter. The anastomosing ridges indicate the spaces between the pustules which cover the interior surface.

The brachial interior is of the complex (*b*) type, with broad, curving posterior ridges, which fade out anteriorly, a short stout median ridge with a finer anterior continuation, and a pair of short, stout lateral ridges separating the anterior and posterior adductor scars; the lateral ridges are continued anteriorly by another set of stout ridges, which are offset slightly toward the median line. The anterior continuations of the median and lateral ridges are not so long in this species as those indicated in the diagram (text figure 5b); the entire muscle area extends only about half the distance from the beak to the point of geniculation of the shell, whereas in some other species of this type, the ridges continue to the geniculation.

Discussion.—*R. camerata* differs from *R. deltoidea* distinctly in its outline and convexity. Whereas *R. deltoidea* has a sharply triangular or subpentagonal outline with a sharp angle in the center of the anterior margin, *R. camerata* has a rounded anterior margin. Whereas *R. deltoidea* has a sharply angular geniculation, occurring about 18 mm. from the beak and forming an angle of about 120°, *R. camerata* has a rounded geniculation about 9–12 mm. from the beak, forming an angle of 90° or less. Raymond stated

that *R. camerata* differs from *R. deltoidea* in having a pustulose pedicle interior. All *Rafinesquinae* have pustulose interiors, but the pseudopunctae of *R. camerata* seem to be coarser, on the whole, than those of *R. deltoidea*.

R. camerata is also closely related to *R. sardesoni* and has been confused with it in the past. For example, Raymond's figures of *R. camerata* (1921) from Craigleith, Ontario, are not *camerata* but *sardesoni;* following Raymond's figures, Kay, in 1935, identified specimens of *sardesoni* from the Dubuque formation of Iowa as *camerata* and listed them under that name. However, *R. sardesoni* is a larger shell in general, has a less convex posterior region, and the geniculation takes place at a much greater distance from the beak, both in relation to size and by actual measurement.

R. camerata differs from *R. deerensis*, another species with which it has been confused, in outline, smaller size, and nature and location of the geniculation.

Types.—Holotype: American Museum of Natural History 699/2, (?) upper Sherman Fall or lower Cobourg, Trenton Falls, Oneida County, New York.

The original description said only "Found by Mr. Vanuxem, in Trenton limestone." Hall stated definitely that the specimen came from Trenton Falls, but this is doubtful, since the writer's collection includes numerous specimens of *Rafinesquina* from Trenton Falls, none of which are like Conrad's. Furthermore, *R. camerata* is rare in the lower Cobourg (the highest limestone at Trenton Falls) but very abundant and characteristic of the upper Cobourg elsewhere. The type specimen was therefore probably found at another locality in Vanuxem's district.

Plesiotypes: Brachial interior, Columbia Univ. 25904, from the upper Cobourg in a quarry 1 mile south of the railroad, south of Picton, Prince Edward County, Ontario; pedicle interior (mold), no. 25903, from the *Cyclospira* zone of the upper Cobourg along Gulf Stream at Rodman, Jefferson County, New York.

Range.—Sherman Fall (1 specimen); Prosser (21 specimens); lower Cobourg (10 specimens) and upper Cobourg (46 specimens). Rare in the lower Cobourg; found at Picton, Prince Edward County, Ontario, and along Atwater Brook, near Martinsburg, Lewis County, New York. Abundant in the upper Cobourg; found at Point Petre, Prince Edward County, Ontario, and especially abundant at Rodman, Jefferson County, New York. There are a few specimens from the Sherman Fall and lower Cobourg that seem to be more nearly allied to this species than to any other although they differ from the typical form: one is broader in proportion to length, and the convexity is less; this form occurs in the lower Cobourg along Sandy Creek near Rodman. Another form is longer in proportion to width than the typical form, and the convexity is greater; this sort occurs in the Sherman Fall along Deer River in Lewis County, in the lower Cobourg at Rodman, and along Atwater Brook near Martinsburg. These variations are much rarer than the typical forms.

In the Prosser, *R. camerata* is also abundant; it occurs at a somewhat higher horizon than the equally abundant *R. deltoidea*, thus preserving the stratigraphic relationship between the two species existing in New York and Ontario, although the Prosser is believed to be of Sherman Fall age rather than Cobourg.

RAFINESQUINA SARDESONI Salmon, n. sp.
Plate 86, figures 35–38

Rafinesquina camerata (Conrad). RAYMOND (part), *1921*, Canada Geol. Survey Mus. Bull. 31, pl. 6, figs. 12, 13; pl. 7, fig. 2.

Rafinesquina camerata (Conrad). KAY, *1935*, Jour. Geology, vol. 43, pp. 578, 582 (listed only).

Outline U-shaped; widest just anterior to the hinge line; lateral margins faintly sinuate anterior to the small convex cardinal ears.

Convexity high; posterior portion flattened, anterior nearly straight; geniculation narrowly curved, about 18 to 20 mm. from the beak, forming an angle of about 90°.

Costellae strongly differentiated, with a large interval of secondaries between the primaries. Pseudopunctae large, in irregular rows. Ratio of length to width generally not very high, about 1:1.33. The shells usually attain a rather large size.

Pedicle muscle area fan-shaped and relatively very large, extending to the geniculа-

tion of the shell. The widest part is near the posterior of the scar, about one-third of its length from the beak. The borders are very vaguely defined; the area is marked by irregular radial ridges, which merge at the border of the area into irregular rows of pustules, which cover the remainder of the interior surface of the shell. The adductor track is broad, with a sharp ridge along the median line. The anterior margin of the muscle area is sinuate.

The brachial interior is of the complex (b) type, rather highly developed. The posterior bordering ridges of the muscle area are large, broad, low, ill-defined swellings of the surface, covered on the posterior slopes with large, sharp pustules. The median ridge is low but more sharply defined than in other species, ending about one-third the distance to the geniculation; it is continued to the geniculation by a much finer ridge. There are lateral ridges within the muscle area which are narrow but strong; they end about evenly with the median ridge, and also are continued anteriorly by finer ridges, which are slightly offset toward the median line. These finer ridges do not extend quite so far anteriorly as the continuation of the median ridge.

Hinge width of the type specimen, 29 mm.; median length, 30 mm. Hinge width at the 15 mm. growth stage, 20 mm.; ratio of length to width, 1:1.33.

Discussion.—*R. sardesoni* differs from *R. robusta* in having a definite geniculation, whereas *R. robusta* has a continuous sharp curvature from the umbo forward. *R. sardesoni* is also much more steeply bent downward on the lateral margins, since the sharply curved geniculation continues all around the shell to the cardinal angles, while in *R. robusta* the curvature is less on the sides than on the anterior.

R. sardesoni differs from *R. camerata* in being larger and less convex over the umbo and in having the geniculation considerably farther from the beak.

Types.—Holotype: Columbia Univ. 25905, Collingwood limestone, Craigleith, Grey County, Ontario. Paratypes: Columbia Univ. 25911, brachial interior, and no. 25912, free pedicle valve, from the Dubuque (Collingwood equivalent) at Kendallville, Iowa.

Range.—Upper Cobourg to Collingwood. Eight specimens were seen from the upper Cobourg of southeastern Ontario; they are slightly smaller than the typical forms and may represent a transition from *R. camerata*. *R. sardesoni* is very abundant in the Collingwood at Craigleith (35 specimens) and in the Dubuque of Iowa (29 specimens).

Subfamily RAFINESQUININAE?
Genus ÖPIKINA Salmon, n. gen.

Strophomena (part). BILLINGS, LESLEY, EMMONS, HALL, WINCHELL, OWEN?, SARDESON.
Leptaena (part). HALL, ROGERS, BASSLER?, OWEN.
Rafinesquina (part). HALL and CLARKE, WINCHELL and SCHUCHERT, BASSLER, OKULITCH, and others.

Genotype, *Öpikina septata* Salmon, n. sp.

Concavo-convex; surface covered with fine radial costellae of several sizes, the smaller ones tending to disappear toward the anterior margin, leaving a space of nearly 1 mm. between the primaries. Concentric lines very fine, only visible on extremely well preserved specimens. Cardinal margins not denticulate.

The pedicle interior shows a very large muscle area in comparison to the size of the entire shell; it usually extends about halfway from the beak to the anterior margin of the shell and may extend farther. The diductor scars are circular to broadly oval, shallow, and not usually well defined. The adductor track is a rather broad ridge, highest in the anterior portion, extending almost to the anterior border of the diductor scars. The dental plates are strong, diverging at an angle of 90°–120°. The visceral area of the pedicle valve is marked off by a low ridge, strongest in the posterior part of the shell at the sides of the delthyrial cavity, and continuing, though fainter, around the entire anterior part of the shell, near the margin.

The brachial interior is more distinctive than that of the pedicle valve. (See text fig. 6.) The cardinal process is stout, with two triangular branches; the myophores make an angle of 90° or more with the plane of the interior surface. They do not extend anteriorly, but in some cases posteriorly, from the seat of attachment.

From each side of the base of the cardinal process extends a curving ridge of adventi-

tious shell material bearing the brachiophores, minute processes on the posterior side of the ridge. There is also a ridge around the entire visceral area of the interior, less strong on the sides but becoming sharper on the anterior, and having a fluted appearance due to the strongly marked vascular system. The ridges near the cardinal margin, bearing the brachiophores, are apparently homologous with the short, curving ridges of adventitious shell material in the brachial interior of *Rafinesquina*.

The median line of the brachial interior of *Öpikina* is marked by a ridge starting at the base of the cardinal process, where it is low and broad, which becomes narrower and sharper toward the anterior. In some species it becomes exceedingly sharp and prominent. There are, in addition, two pairs of lateral septa: the posterior pair divide the posterior adductor scars into two more or less unequal areas; the anterior pair are nearly parallel to the median septum and mark the lateral margins of the anterior adductor scars.

The posterior adductor scars are bounded on the sides and separated from the anterior adductor scars by a prominent broad swelling, which is usually highly pustulose and fluted with vascular markings.

The surface of the visceral area outside the muscle scars is very finely pustulose; it appears smooth to the unaided eye, but with a hand lens or under the microscope is seen to be minutely granular.

The shell structure is very finely pseudopunctate; the pseudopunctae lie close together and are apparently not arranged in any definite order. In this character, as well as in the distinctive brachial interior, *Öpikina* differs markedly from *Rafinesquina*, since the latter genus shows much larger pseudopunctae, easily visible with the unaided eye on weathered specimens, and arranged in definite radial rows between the costellae. (See text figure 1.)

The shell structure of *Öpikina* is most like that of *Strophomena;* but although *Strophomena* has moderately to very fine pseudopunctae, their arrangement is usually like that of *Rafinesquina*—in either single or multiple rows between the costellae. Using the shell structure as a criterion, the three genera may be distinguished, even with only a small fragment of the shell and when it is impossible to observe the relative convexity or the interior. However, a few species of *Strophomena* seem to have a shell structure exactly like that of *Öpikina*, and further study may show that *Strophomena*, too, is polyphyletic.

Öpikina differs from *Leptaena* in the characters of the interior. The pedicle interior of *Leptaena* shows a relatively small muscle area bordered by a sharp ridge; *Öpikina* has a large pedicle muscle area bordered by a much less definite ridge. The brachial interiors of the two genera are quite different: *Leptaena* has but three radial ridges, whereas *Öpikina* has five. They also differ in shell structure, since *Leptaena* has large pseudopunctae spaced far apart, in contrast with the fine, crowded pseudopunctae of *Öpikina*.

Discussion.—The fact that some species of "*Rafinesquina*" differ from the genotype in the interior characters has been recognized by previous authors, both American and European. In the original description of "*Rafinesquina*" *minnesotensis* (*Strophomena minesotensis*), N. H. Winchell (1881) stated that "the interior of the entering valve is very different from the entering valve of *S. alternata*." Öpik in 1930 remarked that the genus *Rafinesquina* is heterogeneous; of the group of species here under consideration, he stated that one division of the genus, exemplified by *R. dorsata* Bekker, differs from the group of *R. "alternata"* in the strong development of the septa in the brachial valve and in the cardinal process, which consists of two plates, each folded once. He also stated that the group of *R. dorsata* is connected to *R. alternata* through *R. minnesotensis inquassa* (Sardeson) (misquoted "*incrassa*"), but that the latter has weaker septa and appears to have an *alternata*-like cardinal process, according to the figures given by Hall and Clarke (1892, pl. 8, figs. 2, 3). A comparison of topotypes of *R. dorsata* Bekker with the syntypes of *R. inquassa* (Sardeson) and with specimens showing the interior of *R. trentonensis* shows, however, that the cardinal processes of the first two are alike in structure (both having the folded plates de-

scribed by Öpik), while that of *R. trentonensis* is different from either, consisting of two unfolded plates.

Range.—The earliest positively identified species of *Öpikina* in North America appear in the Black River group. Various Chazyan species of so-called "*Rafinesquina*" may belong to this genus, but neither the types nor topotype material have been studied, and it is impossible to tell from the descriptions and illustrations alone, whether they are *Öpikina* or some other genus.

In the Black River formations, species of *Öpikina* are abundantly represented; they are found in slightly diminishing numbers in the lower Trenton formations and are gradually displaced by *Rafinesquina*. The youngest known form occurs in the Sherman Fall formation. There are also a few specimens in the collection, of lower Cobourg age, that may belong to *Öpikina*, but the identification is doubtful.

ARTIFICIAL KEY TO THE SPECIES OF ÖPIKINA

A. Greatest curvature at umbo.
  1. Convexity low—nearly straight from umbo forward; very large..... *Ö. ruedemanni*
  2. Convexity high—continuous sharp curvature from umbo forward; small..... *Ö. dorsata*

B. Greatest curvature at some point anterior to umbo.
  1. Geniculation sharply curved, angle about 100°, about 10 mm. from beak..... *Ö. minnesotensis*
  2. Angle between posterior and anterior sections about 120°.
    a. Geniculation rounded, about 10 mm. from beak; outline broadly U-shaped ..... *Ö. septata*
    b. Geniculation sharply angular, about 14 mm. from beak; outline quadrangular ..... *Ö. wagneri*
    c. Geniculation rounded, about 16 mm. from beak; outline broadly rounded, with sharp ears..... *Ö. transitionalis*
    d. Geniculation angular, about 18 mm. from beak; outline broadly U-shaped ..... *Ö. inquassa*

ÖPIKINA SEPTATA Salmon, n. sp.
Plate 87, figures 1–4

?Strophomena incrassata Hall. SAFFORD, *1869*, Geology of Tennessee, pp. 235, 244, 258, 286 (listed only).

Outline broadly U-shaped, widest at the hinge line, ranging from about equal in width and length to much wider than long. Cardinal angles acute, extended to form short, blunt ears. Lateral margins converging rapidly, very gently curved; anterior more narrowly rounded.

Convexity low; posterior portion, including the umbo, very gently curved, almost flat; geniculation evenly rounded, not angular, occurring about 10 mm. from the beak; angle between the posterior and anterior sections about 120°. Geniculation more pronounced in the median part of the margin, flattening out toward the cardinal extremities.

Costellae very fine, differentiated in size slightly in the posterior part of the shell, but not differentiated beyond the geniculation. Number of secondaries between primaries small, ranging from one to three. There are faint diagonal wrinkles between the beak and the cardinal extremities. Growth lines not evident except in the marginal areas of the shell, beyond the geniculation. Shell very finely pseudopunctate.

Pedicle interior very simple; dental lamellae short and stout, diverging at an angle of about 90°; diductor scars occupying about two-thirds the length of the shell, very faintly bordered; adductor tracks visible only as a faint ridge.

Brachial interior with three extremely sharp and high knifelike ridges, highest near the anterior end; the median ridge longer than the lateral pair. There is also a second pair of much fainter lateral ridges posterior to the first. The posterolateral borders of the adductor scars are marked by a low, faint, irregularly notched or feathered swelling. The small triangular brachiophores are situated on the posterior sides of this swelling.

The cardinal process is stout, with club-shaped branches, directed posteriorly; the myophores are marked by a deep groove, covered at the lower end by the chilidium. The interarea is very narrow.

The visceral area is bordered by a rather sharp ridge, irregularly crenulated by vascular markings, which continue outside the ridge to the shell margin and are especially noticeable in the anterior part of the shell.

Hinge width of the type specimen un-

known; one cardinal extremity broken; estimated 20 mm. Median length, 13 mm. Ratio of length to width, 1:1.53.

Types.—Holotype: United States National Museum, Washington, D. C.; brachial interior, Lebanon formation, U. S. Highway 41, three-quarters of a mile south of Knox Brook, 9 miles south of Murfreesboro, Tennessee. Paratypes: Pedicle interior and entire shell, United States National Museum; two brachial interiors and two entire shells, Columbia University, New York City, same horizon and locality.

Range.—Lebanon formation of Tennessee (abundant). It is also known from the Ottosee formation of Virginia.

ÖPIKINA DORSATA (Bekker)
Plate 86, figures 39–44

Rafinesquina dorsata BEKKER, *1921*, Dorpat. (Tartu) Univ. Act. Comm., A, vol. 2, pt. 1, p. 73, pl. 3, figs. 9–13; pl. 5, figs. 4–8.
Rafinesquina dorsata, ÖPIK, *1930*, *idem*, vol. 17, pt. 1, p. 183, pl. 14, figs. 154–160, 165; pl. 21, fig. 261; text fig. 22.

Shell small, outline suboval to pentagonal, with bluntly rounded angles; greatest width anterior to the hinge. A small posterior portion of the shell is flattened, but a sharp curvature begins immediately anterior to the umbo and continues to the anterior margin. Costellae fine and irregularly anastomosing, differentiated in size only on the posterior flattened area; growth lines conspicuous, especially on strongly curved areas of the shell. The brachial valve is nearly flat in the posterior part and sharply geniculate around the margins.

The diductor scars of the pedicle valve occupy about two-thirds of the interior surface of the adult shell and are marked by sharp radial ridges. The adductor tracks consist of a pair of thick ridges separated by a narrow groove.

In the brachial valve, the septa are more highly developed than in any of the American species of the genus. They are extremely high and thin, and the anterior pair are curved inward at the posterior end and outward at the anterior. The lateral margins of the muscle area are marked by a strongly pustulose elevated border. The visceral area is delimited by a sharply elevated ridge, which is broken through irregularly by the vascular canals. Between the muscle area and the marginal ridge, the interior surface appears smooth to the naked eye but finely granulated under a lens.

The only American species that resembles *Ö. dorsata* is *Ö. minnesotensis* (Winchell). The latter is somewhat larger and, although highly convex, has a definite geniculation and a long straight slope in the anterior portion, so that its lateral aspect is quite different. The septa of the brachial interior of *Ö. minnesotensis* are not so high and are nearly straight.

Types.—Holotype: Geol. Museum, University of Tartu, Estonia, No. 154, Middle Ordovician, Kuckers Stage (C_2), approximately equivalent to the lower Trenton of North America; locality, Kukruse, Järve, Estonia. Topotypes: Columbia Univ. 25913, 25914 and 25915, same horizon and locality.

Range.—Early Middle Ordovician of Estonia, so far as known. Not found in the Ordovician of North America. Eighteen specimens.

ÖPIKINA MINNESOTENSIS (N. H. Winchell)
Plate 87, figures 5–11

Leptaena deltoidea (Conrad). OWEN, *1852*, Report of a geological survey of Wisconsin, Iowa, and Minnesota, p. 629, tab. 2B, fig. 10 (not the middle figure).
Strophomena minnesotensis N. H. WINCHELL, *1881*, Minnesota Geol. and Nat. History Survey Ninth Ann. Rept., p. 120.
Strophomena incrassata Safford (not Hall). HALL, *1883*, New York State Geologist Second Ann. Rept., pl. 38(8), fig. 2 (not figs. 1, 3–5).
Strophomena deltoidea (Conrad). LESLEY, *1890*, Pennsylvania 2d Geol. Survey Rept. P4, p. 1125, figs. (in part). Copied from Owen, 1852.
Rafinesquina minnesotensis, HALL and CLARKE, *1892*, New York Geol. Survey, Palaeontology, vol. 8, pt. 1, p. 283 (listed only).
Rafinesquina incrassata Safford (not Hall). HALL and CLARKE, *1892*, *idem*, pl. 8, fig. 2 (not figs. 1, 3–5). Copied from Hall, 1883.
Rafinesquina minnesotensis, WINCHELL and SCHUCHERT, *1893*, Minnesota Geol. and Nat. History Survey Final Rept., vol. 3, pt. 1, p. 401, pl. 31, figs. 25–26, 29 (not figs. 27–28). Fig. 29 copied from Hall.
Rafinesquina minnesotensis, GRABAU and SHIMER, *1909*, North American index fossils, vol. 1, p. 212, fig. 252 (only the interior view; copied from Hall).

Shell relatively small, outline evenly and narrowly rounded; widest at or anterior to the hinge line; cardinal angles bluntly rounded, about 90°. Convexity high; posterior gently rounded, anterior a long

straight slope. Geniculation sharply rounded but not angular, about 10 mm. from the beak, forming an angle of about 100°.

No surface markings are visible on the specimens believed to be the syntypes, which are silicified internal molds of pedicle valves. However, other specimens from the same horizon and locality that appear to be specifically identical with the types have very fine costellae of alternating sizes, and the shell is very finely pseudopunctate.

The pedicle muscle area is nearly circular and occupies about one-half the interior surface. The dental lamellae diverge at an angle of about 120°; the lateral and anterior margins of the muscle area are very faintly marked. The adductor tracks consist of a relatively wide ridge, which is highest at the anterior end. The diductor scars are marked by fine radial ridges. The entire visceral area is limited by a low circular ridge. The interior of the brachial valve shows the median and two pairs of lateral septa, which are highest at the anterior ends, and a sharp ridge around the anterior and lateral margins of the visceral area.

Types.—Syntypes: (?) Univ. Minnesota Museum, Minneapolis, Minn., No. 3521; two specimens, one illustrated by Winchell and Schuchert, 1893, pl. 31, fig. 25; hinge width, about 17 mm.; median length, 15 mm.; ratio of length to width, 1:1.13; other specimen, not illustrated by Winchell and Schuchert, hinge width, about 17 mm.; median length, 16 mm.; ratio of length to width, 1:1.06. Both specimens are silicified internal molds of the pedicle valve. Horizon, Lower Blue (upper Black River, Platteville); locality, Minneapolis, Minn. Topotype: Mold of brachial interior, Univ. Minnesota Museum, No. 5097, from the Platteville limestone at Minneapolis, Minn.

Range.—Platteville of the Upper Mississippi Valley (7 specimens); Chaumont of St. Joseph Island (18 specimens); Rockland (1 specimen); Hull (7 specimens) and Decorah (42 specimens); Cloche Island, Ont.; Iowa, New York, and southeastern Ontario.

ÖPIKINA INQUASSA (Sardeson)
Plate 87, figures 12–14

?Strophomena deltoidea Conrad. OWEN, *1844* Report of a geological exploration of part of Iowa, Wisconsin, and Illinois . . . in 1839, pl. 16, fig. 8, and possibly, pl. 17, fig. 6.

Strophomena incrassata Safford (not Hall, 1847). HALL, *1862*, in HALL and WHITNEY, Report of the geological survey of the State of Wisconsin, vol. 1, p. 42, fig. 16.

Strophomena incrassata Safford (not Hall). HALL, *1883*, New York State Geologist Second Ann. Rept., pl. 38(8), figs. 1, 3–5 (not fig. 2).

Strophomena inquassa SARDESON, *1892*, Minnesota Acad. Nat. Sci. Bull. 3, p. 334, pl. 5, figs. 22–24.

Rafinesquina incrassata Safford (not Hall). HALL and CLARKE, *1892*, New York Geol. Survey, Paleontology, vol. 8, pt. 1, pl. 8, figs. 1, 3–5 (not fig. 2). Copied from Hall, 1883.

Rafinesquina minnesotensis (Winchell) var. *inquassa*, WINCHELL and SCHUCHERT, *1893*, Minnesota Geol. and Nat. History Survey Final Rept., vol. 3, pt. 1, p. 403, pl. 31, figs. 27–28.

Rafinesquina minnesotensis (Winchell). GRABAU and SHIMER, *1909*, North American index fossils, vol. 1, p. 212, fig. 252 (part).

Shell relatively large, outline broadly U-shaped, widest at or just anterior to the hinge line. Cardinal angles bluntly rounded, about 90°. Convexity low to moderately high; posterior section gently rounded, anterior nearly straight; the geniculation is broadly angular, about 120°, occurring about 18 mm. from the beak. Posterolateral margins not geniculate, nearly flat. Some specimens show no geniculation at all but a continuous gentle curvature from the umbo forward. Radial costellae differentiated in size, relatively coarse for the genus. There are frequently short, indistinct, very oblique folds along the cardinal margin; growth lines conspicuous around the geniculation. Shell material very finely pseudopunctate.

Pedicle interior with a very large muscle area, nearly circular, covering about two-thirds of the interior surface. However, the muscle scars are very faintly indicated. The interior structures of the brachial valve are thick and heavy. The septa are distinct but not sharp. The anterior pair of lateral septa are curved sharply outward, nearly at right angles, at the anterior end.

Discussion.—Winchell and Schuchert recognized the affinity between this form and *Ö. minnesotensis* by reducing *inquassa* to a variety of that species. However, a comparison of the types, while it establishes the fact that they are congeneric, leads the writer to feel that *inquassa* must be an independent species, since it is a much larger

form and differs from *Ö. minnesotensis* in outline and convexity.

Ö. inquassa is nearly isomorphous with *Rafinesquina trentonensis*, which occurs at about the same horizon in the Upper Mississippi Valley. In general they may be distinguished (aside from the brachial interiors) by the fact that the beak of *R. trentonensis* is narrower but more protruding, while that of *Ö. inquassa* is broad and lies nearly on a line with the posterior margin. The convexity of *Ö. inquassa* tends to be greatest in the anterior portion of the shell, while that of *R. trentonensis* is greatest at or posterior to the umbo. The slope of the dorsal interarea is likewise different in the two species; that of *Ö. inquassa* is anacline, while that of *R. trentonensis* is almost orthocline. The interareas of *R. trentonensis* are much narrower, especially that of the brachial valve, than those of *Ö. inquassa*. However, the two species can usually be distinguished easily with a hand lens by the difference in the pseudopunctae.

It is sometimes difficult to distinguish small brachial interiors of *Ö. inquassa* from those of *Ö. minnesotensis*, especially when the edges are buried in matrix so that the much greater convexity of *Ö. minnesotensis* cannot be seen. However, the cardinal process of *Ö. minnesotensis* is smaller and more delicate, while that of *Ö. inquassa* is massive, with triangular lobes, directed posteriorly, whereas those of *Ö. minnesotensis* are vertical or directed slightly toward the anterior. The brachial interarea of *Ö. min-*

EXPLANATION OF PLATE 86

All figures about ×1.

FIGS. *1, 2*—*Rafinesquina deerensis* Salmon, n. sp., holotype, Columbia Univ. 25894. Pedicle valve. *1*, Ventral view; *2*, lateral view. (p. 581)

3–5—*R. declivis* (James), syntype, Univ. Chicago 2392. Pedicle valve, figured by Foerste (1910, pl. 5, fig. 12a–b). *3*, Ventral view; *4*, lateral view; *5*, anterior view. (p. 581)

6–8—*R. declivis* (James), syntype, Univ. Chicago 2392. Pedicle valve, figured by Foerste (1910, pl. 5, fig. 12d). *6*, Ventral view; *7*, lateral view; *8*, anterior view. (p. 581)

9–11—*R. declivis* (James), syntype, Univ. Chicago 2392. Pedicle valve, not figured by Foerste. *9*, Ventral view; *10*, lateral view; *11*, anterior view. (p. 581)

12, 13—*R. declivis* (James), topotype, Univ. Chicago 2392. Brachial valve, interior. *12*, Ventral view; *13*, posterior view. (p. 581)

14, 15—*R. praecursor* Raymond, topotype, Columbia Univ. 25895. Pedicle valve. *14*, Ventral view; *15*, lateral view. (p. 582)

16—*R. deltoidea* (Conrad), holotype, Am. Mus. 701/1. External mold of brachial valve. (p. 583)

17, 18—*R. deltoidea* (Conrad), topotype, Columbia Univ. 25896. Pedicle valve. *17*, Ventral view; *18*, lateral view. (p. 583)

19—*R. deltoidea* (Conrad), topotype, Columbia Univ. 25897. Pedicle valve, interior. (p. 583)

20—*R. deltoidea* (Conrad), topotype, Columbia Univ. 25898. Brachial valve, interior. (p. 583)

21, 22—*R. normalis* Wilson, ideotype, Columbia Univ. 25899. Pedicle valve. *21*, Ventral view; *22*, lateral view. (p. 585)

23, 24—*R. normalis* Wilson, ideotype, Columbia Univ. 25900. Pedicle valve. *23*, Ventral view; *24*, lateral view. (p. 585)

25, 26—*R. edmondensis* Salmon, n. sp., holotype, Columbia Univ. 25901. Pedicle valve. *25*, Ventral view; *26*, lateral view. (p. 585)

27, 28—*R. equipunctata* Wilson, ideotype, Columbia Univ. 25902. Pedicle valve. *27*, Ventral view; *28*, lateral view. (p. 586)

29–31—*R. camerata* (Conrad), holotype, Am. Mus. 699/2. Pedicle valve. *29*, Ventral view; *30*, lateral view; *31*, anterior view. (p. 586)

32, 33—*R. camerata* (Conrad), plesiotype, Columbia Univ. 25903. Internal mold of pedicle valve. *32*, Ventral view; *33*, lateral view. (p. 586)

34—*R. camerata* (Conrad), plesiotype, Columbia Univ. 25904. Brachial valve, interior. (p. 586)

35, 36—*R. sardesoni* Salmon, n. sp., holotype, Columbia Univ. 25905. Pedicle valve. *35*, Ventral view; *36*, lateral view. (p. 588)

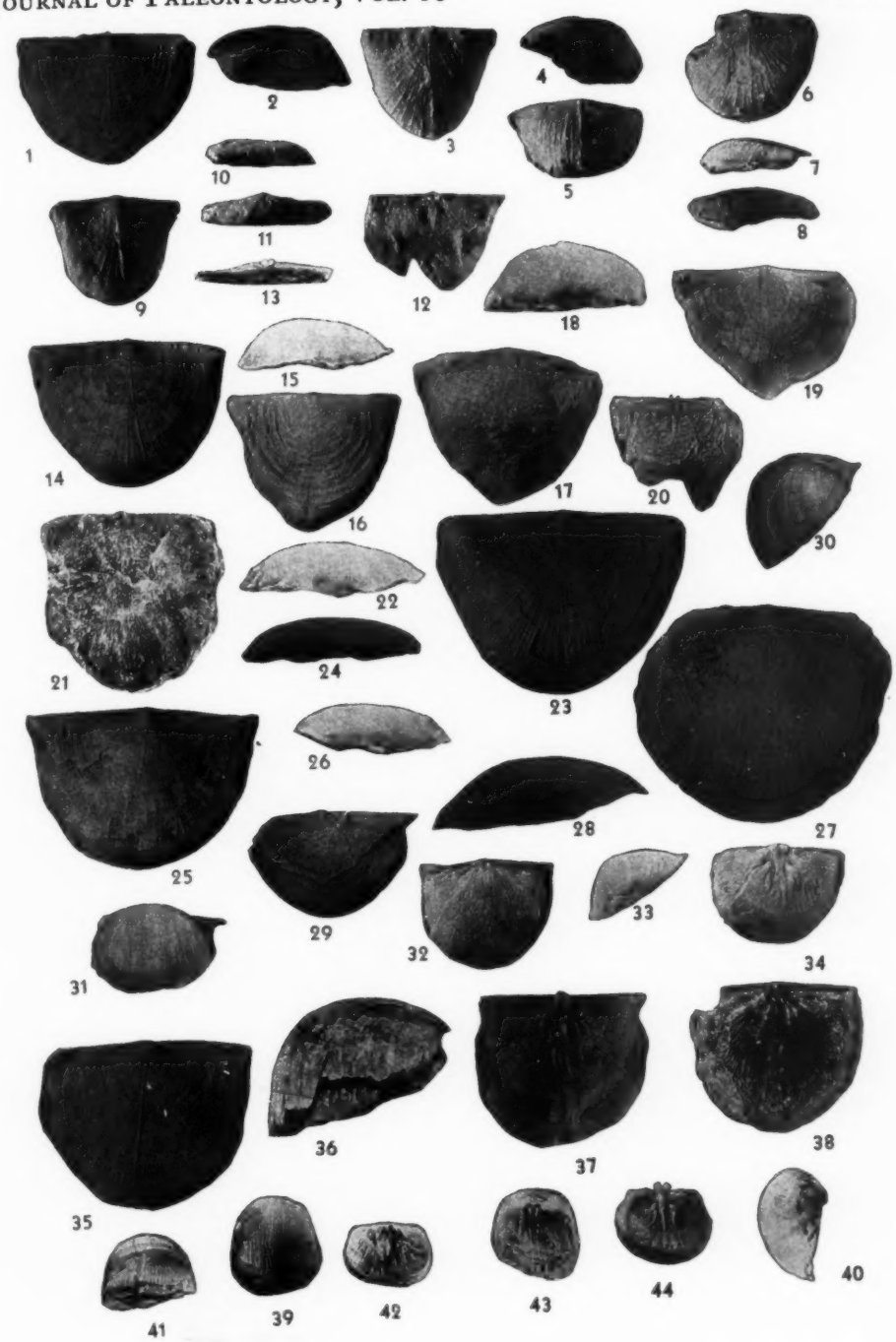
37—*R. sardesoni* Salmon, n. sp., paratype, Columbia Univ. 25911. Brachial valve, interior. (p. 588)

38—*R. sardesoni* Salmon, n. sp., paratype, Columbia Univ. 25912. Pedicle valve, interior. (p. 588)

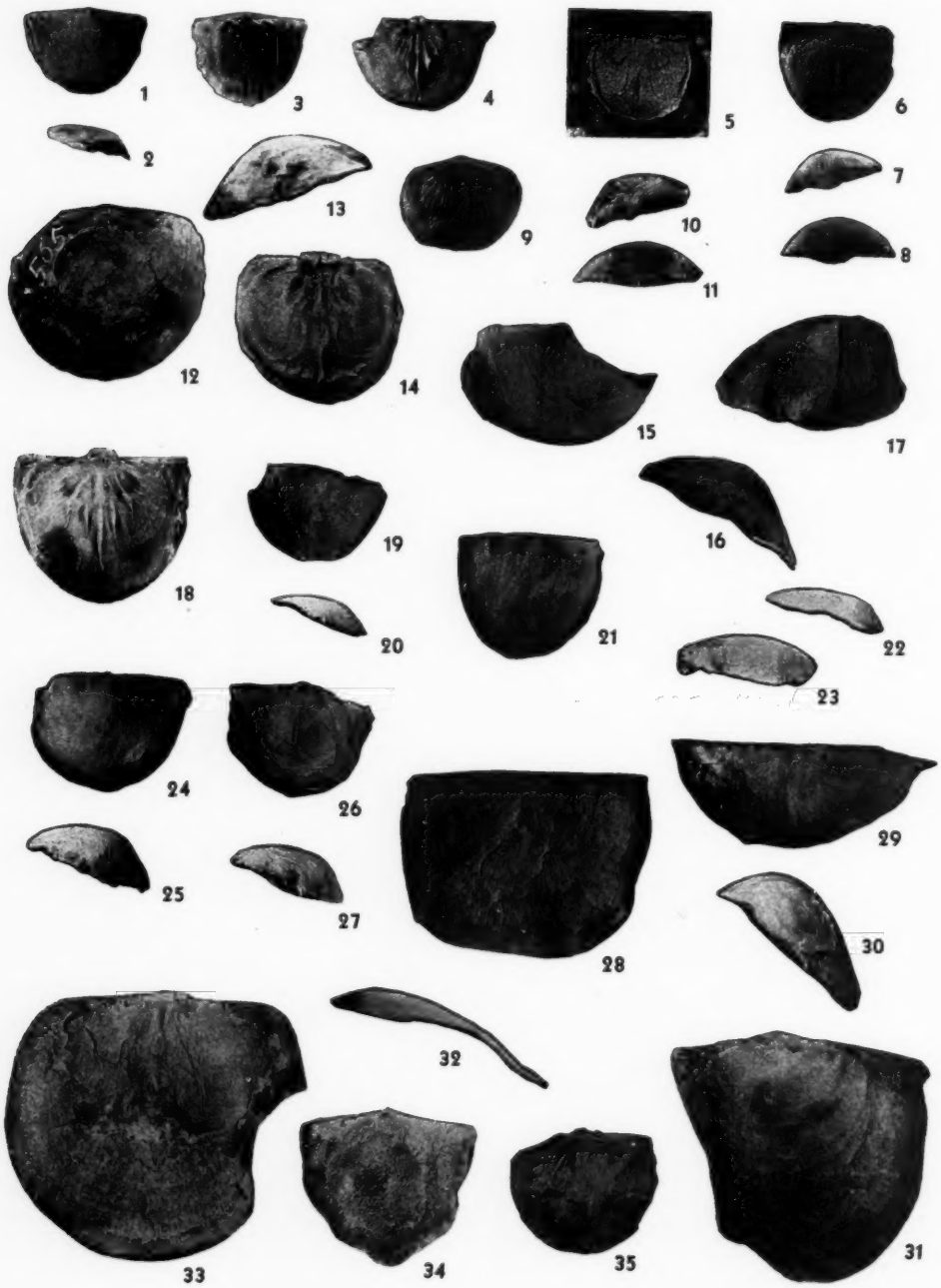
39–41—*Öpikina* dorsata (Bekker), topotype, Columbia Univ. 25913. Pedicle valve. *39*, Ventral view; *40*, lateral view; *41*, anterior view. (p. 592)

42, 43—*Ö. dorsata* (Bekker), topotype, Columbia Univ. 25914. Pedicle valve, interior. *42*, Posterodorsal view; *43*, anterodorsal view. (p. 592)

44—*Ö. dorsata* (Bekker), topotype, Columbia Univ. 25915. Brachial valve, interior. (p. 592)



Salmon, Mohawkian Rafinesquinae



Salmon, Mohawkian Rafinesquinae.

nesotensis is also narrower than that of *Ö. inquassa*.

Syntypes: Peabody Museum, Yale Univ., New Haven, Conn., no. 565, "*Stictopora*" bed (Guttenberg), of Rockland age, St. Paul, Minn.

Range.—Chaumont (12 specimens); Rockland (13 specimens), and Hull (11 specimens), New York and southeastern Ontario. Platteville (4 specimens); Decorah (46 specimens), and Prosser (6 specimens), Upper Mississippi Valley.

ÖPIKINA TRANSITIONALIS (Okulitch)
Plate 87, figures 15–18

Rafinesquina transitionalis OKULITCH, *1935*, Canadian Field Naturalist vol. 49, p. 97, pl. 1, fig. 3 (not fig. 4).

Two specimens are figured by Okulitch with the original description of this species. The specimen designated by Okulitch as the holotype is broken, as shown in the figure cited above, and is in addition somewhat deformed. The original outline, judged from the specimen itself, was probably much less

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EXPLANATION OF PLATE 87

All figures about ×1 unless otherwise indicated.

FIGS. *1, 2*—*Öpikina septata* Salmon, n. gen., n. sp., paratype, U. S. Nat. Mus. Pedicle valve. *1*, Ventral view; *2*, lateral view. (p. 591)

3—*Ö. septata* Salmon, n. gen., n. sp., paratype, U. S. Nat. Mus. Pedicle valve, interior. (p. 591)

4—*Ö. septata* Salmon, n. gen., n. sp., holotype, U. S. Nat. Mus. Brachial valve, interior. (p. 591)

5—*Ö. minnesotensis* (Winchell), topotype, Univ. Minn. 5097. Internal mold of brachial valve, (p. 592)

6–8—*Ö. minnesotensis* (Winchell), syntype(?), Univ. Minn. 3521. Internal mold of pedicle valve. figured by Winchell and Schuchert (1893, pl. 31, fig. 25). *6*, Ventral view; *7*, lateral view; *8*, anterior view. (p. 592)

9–11—*Ö. minnesotensis* (Winchell), syntype(?), Univ. Minn. 3521. Internal mold of pedicle valve, not figured by Winchell and Schuchert. *9*, Ventral view; *10*, lateral view; *11*, anterior view. (p. 592)

12, 13—*Ö. inquassa* (Sardeson), syntype, Yale Univ., Peabody Mus. 565. Pedicle valve. *12*, Ventral view; *13*, lateral view. (p. 593)

14—*Ö. inquassa* (Sardeson), syntype, Yale Univ., Peabody Mus. 565. Brachial valve, interior. (p. 593)

15–17—*Ö. transitionalis* (Okulitch), holotype, McGill Univ., Okulitch Coll. 45 (part). Pedicle valve. *15*, Ventral view; *16*, lateral view; *17*, anterior view (the dark line marks the median costella, showing distortion of the valve). (p. 595)

18—*Ö. transitionalis* (Okulitch), plesiotype, Columbia Univ. 25908. Brachial valve, interior. (p. 595)

19, 20—*Ö. wagneri* (Okulitch), holotype, McGill Univ., Okulitch Coll. 14. External mold of brachial valve. *19*, Ventral view; *20*, lateral view. (p. 596)

21–23—*Ö. "transitionalis"* (Okulitch), McGill Univ., Okulitch Coll. 45 (part). Figured by Okulitch (1935, pl. 1, fig. 4). Pedicle valve. *21*, Ventral view; *22*, lateral view; *23*, anterior view. (=*O. wagneri.*) (p. 596)

24, 25—*Ö. "williamsi"* (Okulitch), syntype, McGill Univ., Okulitch Coll. 5. Figured by Okulitch (1935, pl. 1, fig. 6a). Pedicle valve. *24*, Ventral view; *25*, lateral view. (=*Ö. wagneri.*) (p. 596)

26, 27—*Ö. "williamsi"* (Okulitch), syntype, McGill Univ., Okulitch Coll. 5. Figured by Okulitch (1935, pl. 1, fig. 6b). Pedicle valve, exfoliated. *26*, Ventral view; *27*, lateral view. (=*Ö. wagneri.*) (p. 596)

28—*Ö. clara* (Okulitch), holotype, McGill Univ., Okulitch Coll. 34. External mold of brachial valve, with some shell layers attached. ×1⅜±. (p. 597)

29, 30—*"Rafinesquina grandis"* Okulitch, holotype, McGill Univ., Okulitch Coll. Brachial valve. *29*, Dorsal view; *30*, lateral view. (=*Strophomena* sp.) (p. 598)

31, 32—*Ö. ruedemanni* Salmon, n. sp., holotype, Columbia Univ. 25909. Pedicle valve. *31*, Ventral view; *32*, lateral view. ×⅝±. (p. 597)

33—*Ö. ruedemanni* Salmon, n. sp., paratype, Columbia Univ. 25916. Internal mold of brachial valve, with some shell layers attached. ×⅝±. (p. 597)

34—*Kirkina millardensis* Salmon, n. gen., n. sp., paratype, Columbia Univ. 25918. Pedicle valve, ventral view. The lateral view is not shown, since the central area of the valve is eroded. (p. 599)

35—*K. millardensis* Salmon, n. gen., n. sp., holotype, Columbia Univ. 25917. Brachial valve, interior. (p. 599)

triangular, and the geniculation less sharply angular. The original plane of symmetry is shown in the photograph accompanying the present paper by a dark line along the median line of the pedicle valve, following what appears to be the largest costella.

The other specimen illustrated by Okulitch (1935, pl. 1, fig. 4), is a quite different shell.

Öpikina transitionalis is distinguished from *Ö. inquassa* by the outline of the pedicle valve, which is broadly U-shaped in the latter, with no cardinal ears and a gently curving lateral margin, whereas *Ö. transitionalis* has sharply projecting ears and a sinuous lateral margin. The convexity of the two species is also different: although the angle of the geniculation is the same in both, in *Ö. inquassa* it occurs farther toward the anterior than in *Ö. transitionalis;* in *Ö. inquassa* the geniculation is angular, whereas in undistorted specimens of *Ö. transitionalis* it is rounded.

Hinge width of the holotype unknown (both cardinal angles broken off); median length, 26 mm. The geniculation occurs at about 16 mm. from the beak, making an angle of about 120°. The original outline of the shell was probably broadly rounded. Growth lines indicate that the cardinal extremities were slightly produced, forming an angle of about 80°. The measurements of the other specimen figured by Okulitch are: Length, 19 mm., width, 21 mm.; geniculation at 14 mm. from the beak angle about 120°, and sharply marked around the border of the entire shell, whereas the type of *R. transitionalis* has very gently sloping lateral margins. The outline of the second specimen is almost quadrate, except that the sides converge rather rapidly. The specimen seems to belong to the species *Öpikina wagneri* (Okulitch), to be discussed below.

Types.—Holotype: McGill University, Montreal, P. Q., Okulitch No. 45 (part), Black River group, Chaumont formation, Pointe Claire, P. Q. Plesiotype: Brachial interior, Columbia Univ. 25908, from the Black River group, Chaumont (?), *Leperditia* zone of Rominger (1871, Geol. Survey Michigan, vol. 1, pt. 3), northern shore of St. Joseph Island, Ontario.

Range.—Lowville and Chaumont of Quebec; Chaumont (?), St. Joseph Island, Ontario (67 specimens); Platteville limestone, at Platteville, Ill. (12 specimens); Rockland (4 specimens), Hull (9 specimens), and Sherman Fall (1 specimen), New York and Ontario. Decorah (2 specimens), Upper Mississippi Valley. One of the most common species of *Öpikina* in North America.

ÖPIKINA WAGNERI (Okulitch)

Plate 3, figures 19–27

Rafinesquina wagneri OKULITCH, *1935*, Canadian Field Naturalist, vol. 49, p. 98, pl. 1, fig. 5.
Rafinesquina transitionalis (part) OKULITCH, *1935, idem*, p. 97, pl. 1, fig. 4 (not fig. 3).
Rafinesquina williamsi OKULITCH, *1935, idem*, p. 98, pl. 1, fig. 6.

Outline nearly quadrangular, widest at the hinge line; cardinal extremities extended as short, bluntly angular ears. Lateral margins slightly sinuate anterior to ears, then gently rounded; anterior broadly rounded; anterolateral angles noticeable but not prominent. Convexity moderately high; posterior section gently rounded, geniculation sharply angular, at about 14 mm. from the beak, forming an angle of about 120°. The geniculation continues around the lateral margins to the cardinal extremities.

The pedicle interior is known only from one of the syntypes of *R. williamsi*, which is partly exfoliated. Only the dental plates, diverging at an angle of about 90°, the posterior end of the adductor track, and the faint ridge surrounding the visceral area can be seen on this specimen. The brachial interior is unknown, but the shell material in all specimens is finely pseudopunctate.

Discussion.—*R. wagneri* and *R. williamsi* appear much alike from their original descriptions and figures, the chief difference being the flatness of the posterior portion of the shell in *R. wagneri*, and the lower convexity. These differences are easily accounted for when it is seen that the holotype of *R. wagneri* (which Okulitch considered to be the pedicle valve) is actually the external impression of a brachial valve. This fact likewise accounts for the emphasized concentric lines to which Okulitch referred, which are always more numerous and stronger on the brachial valve. The smaller of the two specimens illustrated by Okulitch as *R. transitionalis* probably also belongs here. It differs from the type of *wagneri*

only in having a more quadrate outline and a slightly lower convexity, but the differences are not of sufficient prominence to warrant making an independent species of it (and it is not conspecific with the holotype of *Ö. transitionalis*).

Öpikina wagneri shows close affinity with *Ö. minnesotensis*, and may, in fact, be a local variation of that species. The main difference between them is that in some specimens of *Ö. wagneri* (for example, one of the syntypes of "*williamsi*") there is a definitely angular geniculation, while in *minnesotensis* the curvature, as a rule, is continuous, with a small radius; in addition, *minnesotensis* is a smaller species, which might be a matter of environment. Otherwise the two species are very much alike. On the other hand, they occur together in a few localities, and there the difference in size is still maintained.

Holotype.—McGill University, Montreal, P. Q., Okulitch No. 14; Black River group, Chaumont formation, St. Vincent de Paul, P. Q. Types of *Ö. "williamsi,"* McGill Univ., Okulitch No. 5, same horizon and locality. Specimen of *Ö. "transitionalis"* (Okulitch, 1935, fig. 4), from the Chaumont at Pointe Claire, P. Q.

Range.—Chaumont (26 specimens), Quebec and St. Joseph Island, Ontario. Rockland (1 specimen), and Hull (8 specimens), New York and Ontario.

ÖPIKINA RUEDEMANNI Salmon, n. sp.
Plate 87, figures 31–33

Rafinesquina alternata (Emmons). RUEDEMANN, *1901*, New York State Mus. Bull. 49, p. 16, pl. 2, fig. 1.

Shell attaining a very large size; ranging from slightly wider than long to much wider than long; cardinal angles acute, extended, sometimes extremely so. Lateral margins sinuate below the ears, then broadly rounded, forming a semicircle with the anterior margin. Convexity low; greatest curvature over the umbo, becoming gradually less towards the anterior. The profile is like that of *R. trentonensis*. Radial costellae very fine; differentiated, but not noticeably on account of their fineness. Concentric lines pronounced, occurring at intervals; diagonal wrinkles along the hinge line very strongly marked. Shell material pseudopunctate, typically öpikinoid, the granules very fine.

The interior of the brachial valve shows the median septum and four lateral septa of *Öpikina*, and the strong internal marginal ridge.

Hinge width of holotype, about 45 mm. (restored); median length, 37 mm. Ratio of length to width, 1:1.215.

Discussion.—In describing the specimens which he had identified as *R. "alternata"* from the Rysedorph conglomerate, Ruedemann stated:

> Many pebbles of the gray crystalline limestone of Rysedorph hill are filled to the exclusion of other fossils with very large specimens of *Rafinesquina alternata*. The extreme size of a great number of specimens, combined with a remarkable extension of the cardinal region, constitutes a striking variation from the type. . . . Numerous other specimens are remarkable for the strong oblique corrugation of their cardinal regions.

The writer has found no specimens among the material studied from Rysedorph Hill that show the extreme cardinal extension of the specimen illustrated by Ruedemann, but the specimens in the collection are all of great size and show the strong corrugation of the hinge margin of which he spoke, and all have the cardinal angles extended to some degree. It is believed that these specimens and those described by Ruedemann are conspecific, and that the species is an undescribed one. It cannot be *Rafinesquina*, since all the specimens show the characteristic pseudopunctae of *Öpikina*, and many show the typical *Öpikina* brachial interior.

Types.—Holotype: Columbia Univ. 25909, pedicle exterior, lower Trenton pebbles in Rysedorph conglomerate, Rysedorph Hill, near Albany, New York. Paratype: Columbia Univ. 25916, brachial interior, same horizon and locality.

Range.—Unknown outside of the type locality. Seventeen specimens.

Other Mohawkian Species Generally Assigned to *Rafinesquina*

ÖPIKINA CLARA (Okulitch)?
Plate 87, figure 28

Rafinesquina clara OKULITCH, *1935*, Canadian Field Naturalist, vol. 49, p. 97, pl. 1, fig. 1.
?Rafinesquina alternata of authors, in lists of Black River fossils.

The holotype of this species and other

specimens identified with it by Okulitch are all external impressions of brachial valves. They are too wide and show too little convexity at the anterior margin to be the brachial valves of such convex species as *Öpikina wagneri* or *transitionalis*. However, Okulitch lists "*Rafinesquina alternata*" in his Black River fauna from the vicinity of Montreal. The writer has, so far, seen no true Rafinesquinas in rocks of Black River age, including the material used by Okulitch, which was borrowed from McGill University for study. It is believed, though it is not certain, that the pedicle valves identified by Okulitch and, probably, by other authors from Black River formations as *R. alternata* may be pedicle valves of *Ö. clara*.

Holotype.—McGill University, Montreal, P. Q., Okulitch No. 34, Black River group, Chaumont formation, Pointe Claire, P. Q.

Range.—As it is not known definitely what the pedicle valve of this species may be, it has been impossible to identify specimens from other localities with it, and the geologic and geographic range is therefore unknown.

STROPHOMENA GRANDIS (Okulitch)
Plate 87, figures 29, 30

Rafinesquina grandis OKULITCH, *1935*, Canadian Field Naturalist, vol. 49, p. 98, pl. 1, fig. 2.

The holotype of this species is a large *Strophomena* of the sort usually identified as *Strophomena filitexta* Hall. The beak of the convex valve is slightly concave, and does not extend beyond the cardinal margin; faint indications of the interior structures showing through the outer shell layers indicate a brachial, rather than a pedicle valve, and the shell structure is typically strophomenoid, like neither *Rafinesquina* nor *Öpikina:*

> The punctae have a tendency to be regularly arranged, and when so, occur in grooves between the costellae . . .

This type of pseudopunctation differs from the *Rafinesquina* type, for whereas in *Rafinesquina* the pseudopunctae are separated from each other by a definite space, in *Strophomena* they are crowded together so closely that they give the shell a scaly appearance although they may be of fairly large size and are usually arranged in rows. In *Öpikina*, on the other hand, the pseudopunctae are always very fine and are crowded together with no arrangement in rows. (See text figure 1.)

RAFINESQUINA RUGOSA Wilson

Rafinesquina rugosa WILSON, *1921*, Canada Geol. Survey Bull. 33, p. 51, pl. 3, figs. 8, 9.

No specimens of this species have been seen in any of the collections. The types are from the

> top of lowest Trenton beds exposed at Stewart Quarry, Rockland, Ontario, and at an exposure of the same horizon about 3 miles east of Ottawa.

From the description and figures, the species may be *Rafinesquina*, *Leptaena* or *Öpikina*.

RAFINESQUINA RUGOSA var. AVITA Wilson

Rafinesquina rugosa var. *avita* WILSON, *1932*, Canadian Field Naturalist, vol. 46, no. 6, p. 133.

No specimens seen. The type is from the "Leray" of Crosby Tp., Leeds County, Ontario.

RAFINESQUINA TENUILINEATA (Conrad)

Strophomena tenuilineata CONRAD, *1842*, Acad. Nat. Sci. Philadelphia Jour., vol. 8, p. 259.

Undeterminable. Figured in 1847 by Hall (as *Leptaena tenuilineata*), who stated that the figure was drawn by Conrad, and that he himself had never seen the species. There are only two other references to it in the literature; both are merely bibliographic citations of the original publication. The species was transferred to *Rafinesquina* by Bassler in 1915. The original horizon was said to be "Trenton limestone," the locality not given.

Genus KIRKINA Salmon, n. gen.

Genotype, *Kirkina millardensis* Salmon, n. sp.

Concavo-convex; surface covered with coarse, sharp, radial costellae, which do not appear to be differentiated in size. Cardinal margin not denticulate. The shell structure is finely pseudopunctate, with the punctae crowded close together and not arranged in any definite order; in this respect the genus is like *Öpikina*. (See text figure 1.)

The brachial interior shows a slender bilobed cardinal process situated upon a tri-

GEOLOGIC DISTRIBUTION OF THE SPECIES OF RAFINESQUINA AND ÖPIKINA[1]

	New York and SE. Ontario									Ky.	Upper Mississippi Valley				
	Black River			Trenton						Trenton	Black River	Trenton			
							Cobourg								
	Pamelia	Lowville	Chaumont	Rockland	Hull	Sherman Fall	Lower	Upper	Collingwood	Cynthiana	Platteville	Decorah	Prosser	Stewartville	Dubuque
R. trentonensis				C	A	C						C	R		
R. elongata												C			
R. lennoxensis				C											
R. olliformis				C[2]											
R. robusta						R[3]		A	R				?C		
R. minuta						R	R	R							
R. prestonensis				R	A	A	?R					R			
R. lewisensis						C	C	C							
R. winchesterensis										A					
R. carlottina					?R	?R	R								
R. deerensis							R	A							
R. declivis										R					
R. praecursor				?		A	R								
R. deltoidea						R	A	R					A		
R. normalis						R	R	R							
R. edmondensis						C									
R. equipunctata				?		R	R	R							
R. camerata						R	R	A					A		
R. sardesoni								R	A						A
Ö. minnesotensis			C	R	?R	?R					C	R			
Ö. inquassa			R	C	R	R					R	C	R		
Ö. transitionalis		R	C	C	R	R					C	R			
Ö. wagneri			R	R	R										
Ö. ruedemanni					?R	A[3]									

R, Rare; C, common; A, abundant; ?, Identification of specimens uncertain.

[1] *Ö. septata*, abundant in the Lebanon of Tennessee, is not included, since the age of the Lebanon is uncertain.

[2] Type locality only.

[3] Rysedorph conglomerate—age uncertain.

angular mass of shell tissue, from which arises a low, broad median septum; at the sides of the cardinal process two broad masses of shell tissue extend diagonally forward along the posterior margins of the adductor scars. The adductor scars are also divided by a pair of very faint lateral septa. In this respect the genus is like *Rafinesquina*, in that it has, at most, three true septa in the brachial interior. (See text figure 7.)

The brachiophores are prominent plates situated on the posterior sides of the low ridges of shell tissue on either side of the cardinal process. The pedicle interior is unknown.

Discussion.—This genus, known only from a small number of specimens from the Pogonip limestone of Utah, seems ancestral to both *Öpikina* and *Rafinesquina* in that it possesses the shell structure of the former and the brachial interior of the latter. Further study is needed to determine its range and clarify its taxonomic position.

KIRKINA MILLARDENSIS Salmon, n. sp.
Plate 87, figures 34, 35

Elongate U-shaped, apparently longer than wide, greatest width at the hinge line or a little below. Cardinal angles blunt, rounded, forming an angle of about 90°. Lateral margins slightly sinuous immediately anterior to the cardinal angles, then

nearly straight, converging rapidly. The anterior margin is narrowly rounded.

The convexity is rather high; the posterior portion sharply rounded, the median portion gently curved, and the anterior sharply curved.

The costellae are relatively coarse, not differentiated in size; the concentric lines are exceedingly fine, almost invisible. There are a few fine growth lines at irregular intervals. The pseudopunctae are very fine and without regular arrangement.

Hinge width of paratype, 23 mm.; median length, 21.5 mm. Hinge width at the 15 mm. growth stage, 20 mm., ratio of length to width, 1:1.33.

The pedicle interior is unknown. The brachial interior resembles that of *Rafinesquina*.

Types. — Holotype: Columbia Univ. 25917, brachial interior; paratype, no. 25918, pedicle exterior on same slab; Pogonip limestone, associated with *Leperditia bivia* White, *Pliomerops nevadensis* (Walcott), *Symphysurus? goldfussi* Walcott, "*Pionodema*" *pogonipensis* (Hall and Whitfield) and *Hesperorthis* sp. The horizon is believed to be equivalent to the Oil Creek formation of Oklahoma. Locality, Point of Rocks, Millard County, Utah.

Range.—Unknown. Eight specimens.

STRATIGRAPHIC SUMMARY

Few, if any, Mohawkian species of *Rafinesquina* and *Öpikina* can be used as guide fossils to a specific formation, because the geographic range of some is too narrowly limited and the geologic range of others is too great. However, assemblages of species are frequently useful as indicators of horizons, as is also the evolutionary stage of the species. The geologic distribution of the species is shown in the accompanying table.

The Black River of northeastern New York, Ontario, and the Upper Mississippi Valley is characterized by the presence of *Öpikina* alone, *Rafinesquina* being absent. No species of *Öpikina* have been seen in rocks of Pamelia age; only one, *Ö. transitionalis*, has been reported from the Lowville. Four species of *Öpikina* are present in the Chaumont of northwestern New York, southeastern Ontario and Quebec. The common species are *Ö. minnesotensis* and *Ö. transitionalis*. The Lebanon formation of Tennessee and the Ottosee of Virginia, which contain abundant *Öpikina septata*, may be Black River or older.

The Rockland formation is easily distinguished from the underlying Black River beds by the presence of *Rafinesquina*. The most plentiful and widespread species of *Rafinesquina* are those of the flatter types, although there are a few highly gibbous species of limited geographic range and rare occurrence. These aberrant forms have not been seen in the Hull formation, in which the dominant type of rafinesquinid is the low, rounded form of shell shown by *R. trentonensis* and *R. prestonensis*. *Öpikina* is still present in both the Rockland and Hull, but in reduced numbers, both as to species and specimens.

With the Sherman Fall formation, the aspect of the rafinesquinids begins to change noticeably. The flat *trentonensis* type is still fairly common, but a number of more convex species make their first appearance at this horizon. There is a difference even in the specimens of *R. prestonensis*, which are larger and more convex than their Hull predecessors. The dominant species of this formation is *R. praecursor;* other common species are *R. lewisensis* and *R. edmondensis*. All three species are definitely more gibbous than the species of the Hull, but not so much so as those of the lower Cobourg. *R. deltoidea* has been considered by some writers as a guide fossil to the lower Cobourg; it cannot be strictly considered so, for it ranges from the Sherman Fall, below, into the upper Cobourg, above. However, it is very abundant in the lower Cobourg, and rare in the other formations, so that its occurrence in great numbers is a strong indication of lower Cobourg age. There are quite a large number of other species in the lower Cobourg, but all are rare except *R. lewisensis*, which is common.

The characteristic species of the upper Cobourg are the highly convex *R. robusta*, *R. deerensis* and *R. camerata*, all very abundant. The tendency to great convexity is carried still further in the Collingwood, in which the only abundant species is *R. sardesoni*.

The youngest specimens of *Öpikina* observed were in beds of Sherman Fall age; they are rare at that horizon and do not appear in younger beds. *Ö. ruedemanni* is locally very abundant in the Rysedorph conglomerate, but no specimens of this species have been found elsewhere.

The Mohawkian formations of the Upper Mississippi Valley contain several species of *Rafinesquina* and *Öpikina* in common with northwestern New York and southeastern Ontario. In the Platteville, there are *Öpikina minnesotensis* and *Ö. transitionalis*, which are common, and *Ö. inquassa*, which is rare. The overlying Guttenberg is characterized by *Rafinesquina trentonensis*, accompanied by a form of local development only, *R. elongata*. There are also rare specimens of *R. prestonensis*, which is an abundant form in the Hull of the eastern area but has not been found in beds younger than Guttenberg in the Upper Mississippi Valley. *Öpikina inquassa* is common in the Guttenberg; *Ö. transitionalis* and *minnesotensis* are rare.

The Prosser formation of this area contains a few specimens of *Ö. inquassa* in the basal beds; there are abundant *R. deltoidea* in the lower beds, and abundant *R. camerata* at a higher horizon; both species are consistently smaller in this area than in New York and Ontario. There are also common specimens of a form resembling *R. robusta* but narrower and less convex. The Prosser has been considered to be of about Sherman Fall age; possibly a part of it may be of Cobourg age, or, on the other hand, it may be that the development of the highly convex types was begun earlier in this region than in the type Trenton area. The Dubuque formation is characterized by abundant *R. sardesoni;* no other species of *Rafinesquina* have been seen at this horizon.

The writer has seen no specimens of *Rafinesquina* from beds older than Cynthiana in the Cincinnati area. The Cynthiana is characterized by abundant *R. winchesterensis* and var. *filistriata*, and rare *R. declivis;* these species have not been seen outside of this area. *R. winchesterensis* is unlike any of the species of the other two areas and most like species of the Cincinnatian; *R. declivis* is most like *R. deerensis*, an abundant upper Cobourg species of New York and Ontario.

POSSIBLE EVOLUTIONARY DEVELOPMENT

Probably both *Öpikina* and *Rafinesquina* were derived from some form such as *Kirkina*, although this cannot be demonstrated, nor can it be determined whether the descent was lineal or collateral, as the geologic range of *Kirkina* is unknown. *Öpikina transitionalis* seems to be nearly isomorphous with *Kirkina millardensis* and is probably the oldest known form of *Öpikina*, unless the Lebanon formation is older than Black River, in which case *Öpikina septata* is the oldest known form. Two lines of development, at least, can be recognized in this genus: namely, a line toward greater convexity and smaller shell size, accompanied by greater complexity of the interior structures, exemplified in America by *Ö. minnesotensis* and in Europe by *Ö. dorsata* and its allies; another line tending toward greater shell size and flatter shell, the interior structures becoming massive, as in *Ö. inquassa* and *ruedemanni*.

Rafinesquina trentonensis has usually been regarded as the most primitive representative of that genus, and it probably is, since it is very simple both in its external appearance and in its interior. The other Rockland species that appeared contemporaneously are much less abundant and quite restricted geographically and were probably local offshoots from the main line of development. Various lines of descent begin to be apparent in the Hull and Sherman Fall. One line emphasized strong curvature of the shell in the posterior portion, starting with *prestonensis* and progressing to *robusta* and *minuta*, the most highly convex, yet not geniculated, forms known.

A second line developed a flattened posterior section and a rather sharp geniculation, located approximately halfway between the beak and the anterior of the *full-grown* shell, so that the "horizontal" and "vertical" components seem to occupy about equal proportions of the shell area. This line of descent culminated in *R. sardesoni*. In this species the interior structures have become more complex, with the development of stronger pustules and vascular markings and more prominent septa, but not massive.

A third line of descent includes forms that have a marked geniculation in the

anterior section of the adult shell. These are the rather large forms which appear flat except for their sharply sloping borders; the horizontal component is much greater than the vertical. This tendency seems to reach its climax in the upper Cobourg, after cinnatian forms, *R. ponderosa* and its allies.

The first two lines apparently died out with the close of the Middle Ordovician; the Cincinnatian species seem to be derivatives of only the third line. Figure 8 is a graphic representation of this scheme of

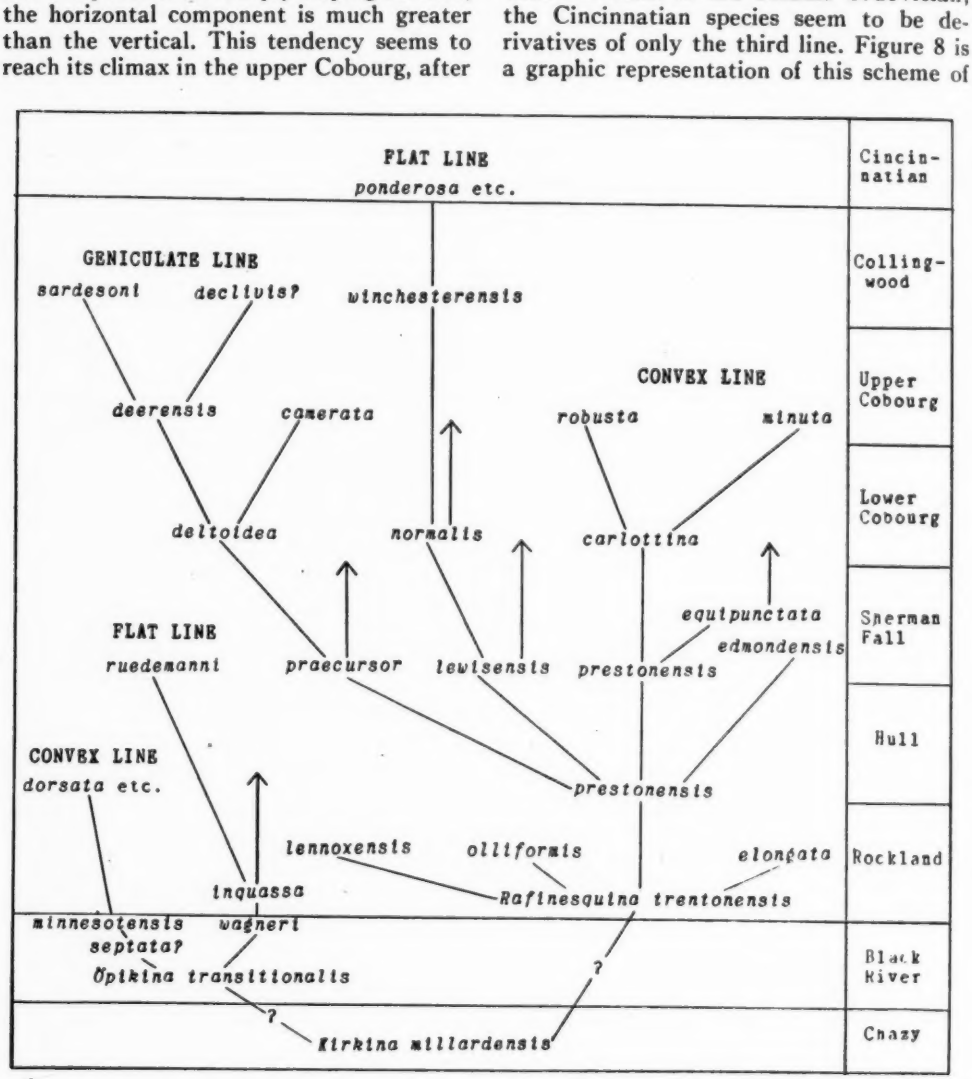

FIG. 8—Lines of development of *Rafinesquina*, *Öpikina*, and *Kirkina*.

which the angle of the geniculation becomes gradually less steep, but the shell has developed a tendency to great size and massive interior characters. The beginnings of this change are seen in *R. winchesterensis* and are developed most fully by the Cincinnatian species.

The relationships of *Öpikina* to *Rafinesquina* and of both genera to other strophomenids is not clear and requires further study. The basis of subdivision of the Strophomenidae is involved in this question.

Schuchert and Levene (1929, *Brachiopoda*, in Fossilium Catalogus, vol. 42), divide the family into two subfamilies, Rafinesquininae and Orthotetinae, apparently on the basis of resupination, with the notation "Arrangement not yet satisfactory." Caster (1938, G. S. A., Bull. 49, p. 1911) has regrouped the crenulate-hinged Strophomenacea of the Silurian and Devonian into one family, regardless of resupination. The writer believes that shell structure may also prove to be a basis for reclassification after further investigation.

For the present it may be said that *Rafinesquina* and *Öpikina*, although they are both concavo convex, are nevertheless quite different in shell structure and interior, and that *Öpikina* shows an apparently closer affinity with some species of *Strophomena* than with *Rafinesquina*, while other species of *Strophomena* have shell structure somewhat like but not identical with that of *Rafinesquina*.

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BRACHIOPODA OF THE CEDAR VALLEY BEDS OF IOWA

Inarticulata, Rhynchonellacea and Rostrospiracea

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ABSTRACT—Eighteen species and four varieties of brachiopods from the Upper Devonian Cedar Valley limestone are described; four species and four varieties as new. The genera represented are distributed as follows: atremes—*Lingula;* neotremes—*Crania, Petrocrania, Lingulodiscina* and *Orbiculoidea;* rhynchonelloids—*Camarotoechia, Hypothyridina* and *Camerophoria;* Rostrospiracea—*Athyris, Meristella* and *Charionella. Athyris nettlerothi* Stainbrook, n. sp., is described from the Middle Devonian Jeffersonville limestone of Indiana.

INARTICULATE brachiopods are rare in the Cedar Valley beds as well as in other late Devonian faunas of adjacent states. This paucity of examples is partly explained by the lithology of the formation. Most of the Cedar Valley is relatively pure limestone with argillaceous phases uncommon. At Buffalo, the *bellula* zone is locally a calcareous shale, and the only atremes secured occur therein. Also these inarticulate brachiopods are small, mostly ectoparasitic, and lack of specimens may be due in part to inadequate search for them. Most species are known from less than half a dozen specimens each.

The Rhynchonellacea likewise form a relatively minor part of the brachiopod fauna of the formation. Examples of *Camarotoechia* occur in nearly every zone, sometimes abundantly, as in the upper beds, but only one species apparently is present. *Hypothyridina* appears first in the Independence shale beds below the Cedar Valley and is present in the basal *independensis* and *profunda* zones. Specimens are never common, as shown by the collection of less than three dozen in a period of sixty years. It is absent from the remainder of the Cedar Valley but occurs in the superjacent Shellrock limestone for its last appearance in the Devonian of Iowa. *Hypothyridina cuboides* (Sowerby) has been regarded generally as marking the base of the Upper Devonian (Williams, 1890). As several American Hypothyridinas have been identified with that species, the genus has assumed an important place in American stratigraphy (Walcott, 1884; Thomas, 1920). Our species, however, are distinct from *Hypothyridina cuboides* but do occur in faunas which apparently are Upper Devonian. In the Independence shale is a species very close to *Hypothyridina emmonsi* (Hall and Whitfield), which Merriam (1940, p. 59) placed in the basal beds of the Upper Devonian of Nevada. Our form occurs with species of *Cyrtospirifer, Macgeea,* and *Nortonechinus,* and species closely akin to *Stropheodonta calvini* Miller, *Strophonella reversa* Hall, and *Spirifer orestes* Hall and Whitfield—all fairly indicative of Upper Devonian age. *Hypothyridina intermedia* and the variety *magniventra* are members of brachiopod faunas that show little or no relationship, specifically, with those of the Middle Devonian of eastern North America. In Iowa, *Hypothyridina* appears to be Upper Devonian.

Three species of *Camerophoria* have been collected. All were known previously under different generic names, but serial sectioning demonstrates that they represent that genus. Examples are few, but they have been collected in most of the zones above the basal *independensis.*

Specimens of *Athyris* occur abundantly in the Cedar Valley and locally in some beds may be the dominant type of fossil. Examples occur throughout the formation and exhibit considerable variation, which is probably correlated with bottom and water conditions. Some of the variations appear to be stable, are useful in stratigraphy, and have, therefore, been given varietal designation. The specific name *vittata* has been applied in other areas to species of *Athyris* which are distinct. One of these is the large *Athyris* found in the Jeffersonville limestone of southern Indiana. This form is here named

Athyris nettlerothi Stainbrook, n. sp., in order to clear up the synonymy of *Athyris vittata*. The need for more precise specific identifications based on comparison of specimens is shown in this case. Faunal lists, unaccompanied by illustrations, are often misleading and may result in erroneous correlations. The other genera of the Rostrospiracea occur only in the *profunda* zone.

Most of the genera discussed in this paper are represented by one or two species, but they are of greater value in correlating strata over wide areas than the more highly variable genera such as *Atrypa* and *Stropheodonta*. Evidence afforded by the species in this paper adds weight to the correlations made in previous papers (Stainbrook, 1935, 1940 and 1941).

Lingula milwaukeensis, *Lingulodiscina marginalis*, *Orbiculoidea telleri* and *wardi*, *Athyris vittata* vars. *randalia* and *brandonensis* occur in the Milwaukee formation of Milwaukee, Wis., and emphasize its relationship to the Rapid (Stainbrook, 1941) member of the Cedar Valley. Other species from Milwaukee probably should be added to this list. *Craniella hamiltoniae* Cleland seems to be *Crania famelica* Hall, and *Camerotoechia contracta saxatilis* Cleland is probably *Camarotoechia cedarensis* Stainbrook.

Several of the species have been reported from the extension of the formation in Illinois, and further search will probably reveal others. *Meristella parva* Cooper and Cloud emphasizes the equivalency of the *profunda* zone of the Cedar Valley to the basal beds of the Devonian section exposed near Kritesville, Calhoun county, Ill. (Cooper and Cloud, 1938, and Stainbrook, January 1941).

In limestone near Annada, Mo., *Athyris vittata* var. *randalia* occurs in moderate numbers. Its weight, therefore, is added to that of other species in correlating the Annada strata with the Rapid member of the Cedar Valley. The presence of *Pugnoides swallovi* (Branson) in the Cedar Valley reinforces the correlation previously made by the writer and others (Savage, 1925, Stainbrook, 1935) with the Mineola limestone of central Missouri. *Pugnoides halli* (Branson), originally described from the Callaway of Missouri, is present high in the Cedar Valley and *Crania famelica* also occurs in both terraces.

Evidence is accumulating, as this study of the Cedar Valley brachiopods proceeds, that the Callaway is linked faunally with the upper beds of the Cedar Valley, especially the Rapid member, and that the Mineola is related to the higher beds of the Solon member. There is little faunal evidence that the fossiliferous Mineola should be correlated with the relatively unfossiliferous Wapsipinicon. They are completely different faunally and rather different lithologically. It would be more logical to assume that the Mineola correlates with the Cedar Valley, inasmuch as there are a number of species common to the two formations. The uppermost members of the Wapsipinicon apparently are completely barren, and the basal beds only carry several species of fossils which are totally different from those of Mineola. The Ashland limestone (Branson, 1941) on the basis of its main fossil, *Rennselandia missouriensis* (Swallow), correlates with the uppermost layers of the *profunda* zone in Iowa. Since there are 20 to 60 feet of Cedar Valley below in apparent conformability, the suggestion of Branson (1941, p. 83) that the Ashland may be present in Iowa as patches, which furnished the specimens to the *profunda* zone, seems untenable. That the Ashland may be undifferentiated from the Cedar Valley may be true, but there is the greater probability that the Missouri formation is simply the southern extension of this portion of the *profunda* zone.

The Devonian strata of northeast Missouri are notably patchy, variable in thickness, and the unconformities above and below the Ashland would not necessarily be present in Iowa. The outcrops of the Missouri Devonian lie on the flanks of the Ozark uplift. The coast line probably was not far away, and consequently the strata there might be expected to record more unconformities than the Cedar Valley beds deposited in areas farther out in the basin, where conditions were more uniform.

The specimens mentioned in the text whose numbers are preceded by the letters S.U.I. are in the collection of the State University of Iowa. Those marked C.H.B. are in the Belanski collection, at present in

the repository of the State University at Iowa City, Iowa. Those preceded by M.A.S. are in the writer's collection made subsequent to his studies at the University. Eventually they will be added to the University collection.

The figures on the plates are all natural size or nearly so. The cross sections of the several species were cut at more or less irregular intervals, where structures first appeared or where disappearance of structures seemed more significant. The pedicle valve is uppermost in the diagrams.

SYSTEMATIC DESCRIPTIONS

Class BRACHIOPODA Cuvier
Order ATREMATA Beecher
Superfamily LINGULACEA Waagen
Family LINGULIDAE Gray
Genus LINGULA Bruguière

LINGULA MILWAUKEENSIS Cleland?

Lingula milwaukeensis CLELAND, *1911*, Wisconsin Geol. and Nat. History Survey Bull. 21, p. 69, pl. 12, figs. 3, 4.

At Buffalo in an argillaceous layer of limestone, two specimens of a *Lingula* have been collected. They are small and present few characters by which they may be identified. They appear to be the same as the *Lingula* from Milwaukee Devonian beds described by Cleland. The smaller but complete individual measures 4.6 mm. in length and 2.5 mm. in width. The larger is in complete, being a single valve with anterior and posterior ends missing. It probably was about 1 cm. long and 6.8 mm. wide.

Occurrence.—Cedar Valley limestone, *bellula* zone, Buffalo, Iowa.

Types.—Hypotypes, Belanski collection 6400 and 6460.

Order NEOTREMATA Beecher
Superfamily DISCINACEA Waagen
Family TREMATIDAE Schuchert
Genus LINGULODISCINA Whitfield

LINGULODISCINA MARGINALIS (Whitfield)

Plate 88, figures 43, 45, 46

Discina marginalis WHITFIELD, *1880*, Wisconsin Geol. Survey Ann. Rept., p. 70.
Discina marginalis, WHITFIELD, *1882*, *idem*, vol. 4, p. 325, pl. 25, fig. 11.
Orbiculoidea marginalis, HALL and CLARKE, *1892*, Paleontology New York, vol. 8, pt. 1, p. 127, pl. 4F, fig. 17.
Lingulodiscina marginalis, CLELAND, *1911*, Wisconsin Geol. and Nat. History Survey Bull. 21, p. 84, pl. 12, figs. 11, 12, 13.

Pedicle valve oval, of medium size, flattened or slightly convex; apex as preserved is scarcely elevated and is situated halfway between the center of the valve and the margin. A small ridge is apparent on the internal mold of the apical region, where the shell is missing. On a part of the shell where the surface of the valve is preserved are shallow, indistinct, well-separated, concentric furrows and very fine numerous radiating lines, more or less exposed by the scaling of a part of the thin porcellaneous shell substance. On the external mold are strongly impressed, fairly deep, linear depressions, concentrically oval, and separated by regular, flat interspaces as much as 0.5 mm. in width; these represent the shallow furrows and interspaces of the unworn surface.

A distorted brachial valve has most of the exterior present. Growth wrinkles are numerous, fine, crowded and slightly lamellose. Every fourth or fifth one is larger. The beak is slightly protuberant and situated adjacent to the margin.

EXPLANATION OF TEXT FIGURES 1–6

FIGS. *1a–j—Camerophoria swallovi* (Branson). A series of nine cross sections, ×5, of the rostral part of a hypotype showing the median septa and the cruralium and spondylium. (p. 614)

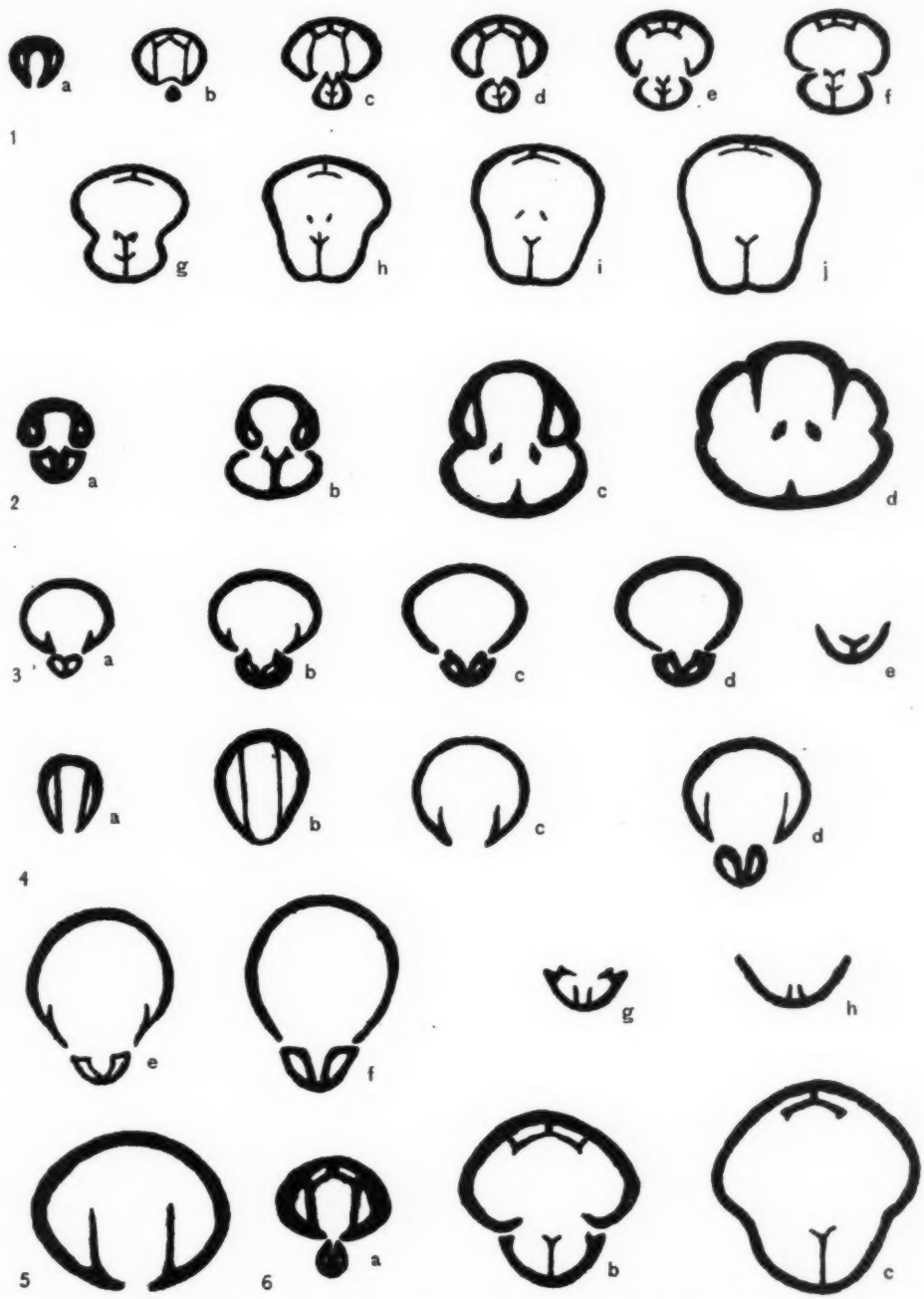
2a–d—Camarotoechia cedarensis Stainbrook, n. sp. A series of four cross sections, ×5, of the rostral part of a paratype showing the dental lamellae and the short brachial septum. (p. 611)

3a–e—Meristella parva Cooper and Cloud. A series of five cross sections, ×6, of the rostral part of a hypotype; the last is of the brachial valve only. It will be noted that the characters shown in the brachial valve differ from those illustrated by Weller from Mississippian species. (p. 618)

4a–h—Charionella? nortoni Stainbrook, n. sp. A series of eight cross sections, ×5, of the posterior part of a paratype; the last two are of the brachial valve only. (p. 619)

5—Hypotyridina intermedia (Barris). A cross section, ×5, of the beak of a pedicle valve showing the short dental lamellae. (p. 612)

6a–c—Camerophoria gregeri (Branson). A series of three cross sections of a hypotype, ×5 showing the septa in both valves and the spondylium and cruralium. (p. 615)



FIGS. 1–6—Cross sections of Brachiopoda. For details see opposite page.

Two of the hypotypes are attached to a specimen of *Conularia molaris* White, one slightly overlapping the other. The larger one measures 15.6 mm. across the least diameter, and the smaller measures 13.2 mm. in the widest part. The largest specimen at hand, attached to a specimen of *Spirifer iowensis*, measures 26 mm. in diameter.

Occurrence.—Cedar Valley limestone; rare in the *independensis* zone at Waverly and in the *bellula* zone at Linder's Boathouse, north of Iowa City, Iowa.

Types.—Hypotypes, S.U.I. 6-505, 6-506, and M.A.S. 38 and 789.

Family DISCINIDAE Gray
Subfamily ORBICULOIDEINAE Schuchert and LeVene
Genus ORBICULOIDEA d'Orbigny
ORBICULOIDEA WARDI Cleland

Orbiculoidea wardi CLELAND, *1911*, Wisconsin Geol. and Nat. History Survey Bull. 21., pp. 85–86, pl. 12, figs. 14–16.

There is at hand a single nearly complete brachial valve of this species. It is small, 5.2 mm. in diameter, nearly circular in outline, and depressed conical in shape. The apex is about halfway between the center of the valve and the posterior margin. The surface slopes strongly and evenly to the anterior and lateral margins and abruptly posteriorly. Externally the valve is marked by many fine concentric growth ridges and by numerous very fine radiating striae. The shell substance is porcellaneous and has a characteristic luster.

Occurrence.—Cedar Valley limestone in the *waterlooensis* zone. The specimen is attached to an *Atrypa gigantea* Webster.

Types.—Hypotype, M.A.S. 366.

ORBICULOIDEA TELLERI Cleland

Orbiculoidea telleri CLELAND, *1911*, Wisconsin Geol. Survey Bull. 21, p. 85, pl. 12, figs. 9, 10.

Several specimens of *Orbiculoidea* agree with the species *telleri* as briefly described and illustrated by Cleland. They are roughly circular, strongly depressed convex, highest at the apex, which is situated about one-fourth the diameter from the posterior border. The surface slopes gently toward the front from the apex but is concave on either side. The shells are attached to the plicate shells of *Stropheodonta*, and only the brachial valve is visible.

The shell substance is white and porcellaneous. The surface is slightly wrinkled concentrically and radially and marked by numerous concentric striae and fine wrinkles of growth. There are also minute radial striae, which are much less marked than those of *Orbiculoidea wardi* Cleland. The largest example at hand has a major diameter of 12.5 mm.

Occurrence.—Cedar Valley limestone in the *bellula* zone at Buffalo, Iowa; Milwaukee formation in all zones at Milwaukee, Wis.

Types.—Hypotypes, M.A.S. 1293 and C.H.B. 6395 and 6572.

Superfamily CRANIACEA Waagen
Family CRANIIDAE King
Genus CRANIA Retzius
CRANIA FAMELICA Hall and Whitfield
Plate 88, figures 36–40

Crania famelica HALL and WHITFIELD, *1872*, Descriptions of new species of fossils, p. 17, pl. 88, figs. 6, 7.
Crania famelica, HALL and WHITFIELD, *1873*, New York State Cab. Nat. History Ann. Rept. 23 p. 236, pl. 11, figs. 6, 7.
Crania famelica, BRANSON, *1923*, Devonian of Missouri, vol. 22, p. 72, pl. 11. figs. 1, 2.
Crania famelica, FENTON and FENTON, *1924*, Michigan Univ. Contr. Mus. p. 80, pl. 19, figs. 1–3.
Philhedra famelica, GREGER, *1909*, Am. Jour. Sci., vol. 27, p. 376.
Craniella hamiltonae CLELAND, *1911*, Wisconsin Geol. Survey Bull. 21, p. 86, pl. 12, figs. 7, 8.

Pedicle valve attached by its entire surface. It is very thin, subcircular in outline, and closely follows the contour of the surface upon which it rests, being corrugated if the host is corrugated and smooth if the host is smooth. A small conical callosity, probably the site of the muscle scars, is situated near the center; concentric growth lines are apparent near the periphery of the valve.

Brachial valve depressed conical, subcircular in outline; apex smooth, rounded, a little eccentric, and forming the highest point of the valve. The surface in most specimens reflects the undulations of the surface of the host, but is more or less smooth. Several specimens show minute radiating striae where the shell substance is worn and numerous lines of increment.

Measurements of several hypotypes are: one is 12 mm. in diameter and 3.5 mm. in

height; another shows a diameter of 18.5 mm. in the widest part and least diameter of 16 mm.; a third measures 16.5 mm. in diameter.

Crania famelica was originally described from specimens from the Cerro Gordo beds of the Lime Creek shales of northern Iowa. The material at hand from the Cedar Valley limestone cannot be differentiated successfully from the Lime Creek form. In general, however, the Cedar Valley specimens are larger in size and do not partake to such an extent in the markings of the host shells. The host species on which this *Crania* has been observed are: *Atrypa*, several varieties, *Spirifer iowensis*, *Athyris vittata*, *Stropheodonta parva*, and *Gomphoceras* sp.

Externally *Crania famelica* resembles *Petrocrania hamiltoniae* (Hall), and few differences are discernible. Both are variable in shape, being more or less circular, smooth externally and may or may not partake in the external markings of the host shell. The pedicle valve is very thin and has but little similarity to that of *Petrocrania hamiltoniae*. There is no thick external rim, nor are the muscle scars strongly developed. The peculiar vascular grooves of *Petrocrania* are not present on any of the pedicle valves at hand, and our species may, therefore, be retained in the genus *Crania*.

Occurrence.—Cedar Valley limestone; it has an extended range in this formation, as it has been collected from the *independensis*, the *bellula*, *waterlooensis*, and *cranaena* zones. It has been found more commonly near Independence, Linn Junction, Iowa City, Buffalo, and Randalia. This species occurs also in the Lime Creek shales and in the Independence shale. *Crania famelica* is also reported from the Snyder Creek shale and Callaway limestone of Missouri.

Types.—Hypotypes, S.U.I. 6-500, 6-501, 6-520 and M.A.S. 166, 255.

CRANIA SHELDONI White
Plate 88, figures 41, 42

Crania sheldoni WHITE, *1862*, Boston Soc. Nat. History Proc., vol. 9, p. 29.
Crania sheldoni, SCHUCHERT, *1897*, U. S. Geol. Survey Bull. 87, p. 192.

Dorsal valve circular or subcircular in outline, irregularly convex, beak somewhat elevated, smooth, inclined backward, and situated near the posterior margin. Surface marked by numerous distinct, fine, somewhat rugose striae. Ventral valve unknown.

This species bears some resemblance to *C. crenistriata* Hall of the Hamilton group of New York, but it is distinct from that in the character of the striae, the convexity of the ventral valve, and in the position of the beak. Locality and position: in the calcareous shales of the age of the Hamilton group of New York, New Buffalo and Iowa City.—WHITE 1862.

The several specimens at hand have all the characteristics mentioned in the above description. The largest measures 13.5 mm. across the largest diameter and approximately 5.5 mm. in height. Another measures 7.6 mm. in diameter and 2 mm. in height. The outline is more oval than circular. The radiating costae are fairly coarse, rounded at their summits, and separated by furrows half as wide. Increase is by intercalation and division, unevenly accomplished so that the costae do not radiate regularly from the apex. The surface slopes with moderate rapidity to the margin and may be concave posterior to the apex. In two specimens the pittings and undulations of the surface on which they rest are reflected in the surface of the brachial valves.

Schuchert has suggested that *Crania sheldoni* is the same as *Crania crenistriata* Hall of the eastern Devonian. A specimen of *Crania sheldoni* from Iowa was compared with the type of *Crania crenistriata* in the American Museum of Natural History and was found to differ in the more eccentric position of the apex and in having slightly finer and more crowded costae. The type specimens of *Crania sheldoni* preserved in the museum of the University of Michigan also show that eccentricity of the apex is pronounced and characteristic. *Crania sheldoni* otherwise differs but little externally from *Crania crenistriata*.

However, internal characters of *Crania sheldoni*, now unknown, may differ from those of *Crania crenistriata*. A species of *Crania* in the Independence shale shows no differences from the Cedar Valley form. The divergent nature of the costae given by Belanski (1928, p. 186) as a distinguishing feature of his *Crania millepunctata* also is seen in *Crania crenistriata* from Thedford, Canada, in *Crania sheldoni* and in the Independence shale form. Future study with more specimens which display the internal

characters may show these forms to be one species. Barris (1899) did not recognize *Crania sheldoni*, as we find him listing the two *Cranias* of the Davenport region as *Crania crenistriata* and *Crania hamiltoniae*. These seem to be the species identified in this work as *Crania sheldoni* and *Crania famelica*.

Occurrence.—Cedar Valley limestone in the *independensis* and *bellula* zones. Specimens have been obtained at Buffalo, Linwood, Shellsburg, Independence, and Davenport. It also occurs in the Independence shale.

Types.—Holotype and paratype University of Michigan Museum 4844. Hypotypes, S.U.I. 6-131 and M.A.S. 37 and 39.

PETROCRANIA sp.
Plate 88, figure 44

In the Coralville member of the Cedar Valley occurs a species of *Petrocrania* which is represented by several incomplete examples. The enclosing limestone is so hard and tough that specimens are recovered chiefly as internal molds of the pedicle valve. In outline this *Petrocrania* is nearly circular, with a slightly truncate posterior margin. One example measures 16.4 mm. in length (incomplete) and 17.8 mm. in width. The posterior scars are large, oblong, and distant from each other. The anterior pair, situated near the elevated center of the valve, are smaller and closer together. The features preserved are insufficient to determine if it is specifically identical with a known species or whether it is a new form. A suggestion of vascular sinuses similar to those of *Petrocrania* suggest reference of the specimens to that genus.

Occurrence.—Cedar Valley limestone in the *Cranaena* zone of the Coralville member.

Types.—M.A.S. 172 and C.H.B. 6734.

EXPLANATION OF PLATE 88

FIGS. *1–4—Hypothyridina intermedia* var. *magniventra* Stainbrook, n. var. Pedicle, brachial, anterior, and lateral views of the holotype, M.A.S. 794; upper part of the *profunda zone*, Solon, Iowa. (p. 613)

5–7—Hypothyridina intermedia (Barris). *5, 6*, Brachial and anterior views of a hypotype; M.A.S. 790. *7*, Anterior view of another. Both from the *independensis* zone, Solon, Iowa. (p. 612)

8, 9—Hypothyridina cf. *H. emmonsi* Whitfield. Lateral and anterior views of a specimen from the Independence shale at Brandon, Iowa. (p. 613)

10–15—Camarotoechia cedarensis Stainbrook, n. sp. *10–12*, Pedicle, brachial and lateral views of a larger than average paratype. S.U.I. 6-320, Iowa City, Iowa. *13, 14*, Pedicle and brachial views of a paratype, M.A.S. 252, Randalia, Iowa. *15*, Anterior view of paratype, S.U.I. 6-320, Iowa City, Iowa. (p. 611)

16–21—Camerophoria gregeri (Branson). *16–18*, Pedicle, brachial and anterior views of a hypotype from Missouri, S.U.I. 6-410. *19–21*, Pedicle, brachial and anterior views of a hypotype, S.U.I. 6-230, from Scott county, Iowa. (p. 615)

22–28—Camerophoria swallovi (Branson). *22–24*, Pedicle, brachial and lateral views of a hypotype, S.U.I. 6-321, Brandon, Iowa. *25*, Brachial view of a smaller specimen. *26–28*, Pedicle, brachial and anterior views of a smaller hypotype, S.U.I. 6-411, Linn Junction, Iowa. (p. 614)

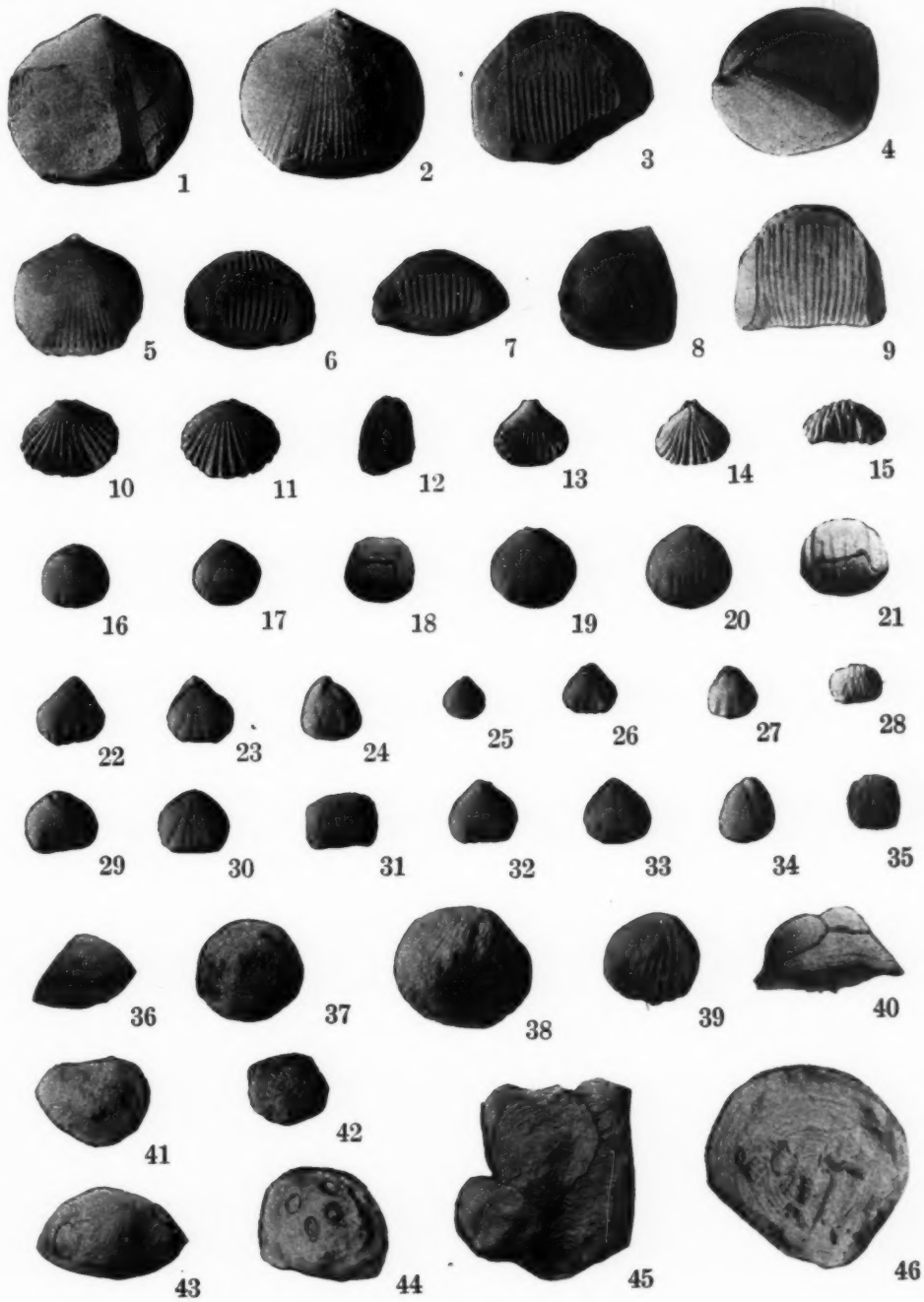
29–35—Camerophoria subovata (Savage). *29–31*, Pedicle, brachial and lateral views of a hypotype, S.U.I. 6-315. *32–34*, Pedicle, brachial and lateral views of a hypotype, M.A.S. 136. *35*, Anterior view of another. All from the *cranaena* zone, east of North Liberty, Iowa. (p. 613)

36–40—Crania famelica Hall and Whitfield. *36*, Lateral view of a hypotype, M.A.S. 166, Buffalo, Iowa. *37–39*, Pedicle views of three hypotypes, S.U.I. 6-500, 6-501A, B. *40*, Lateral views of two specimens on a larger one, S.U.I. 6-520, *independensis* zone, Linn Junction, Iowa. (p. 608)

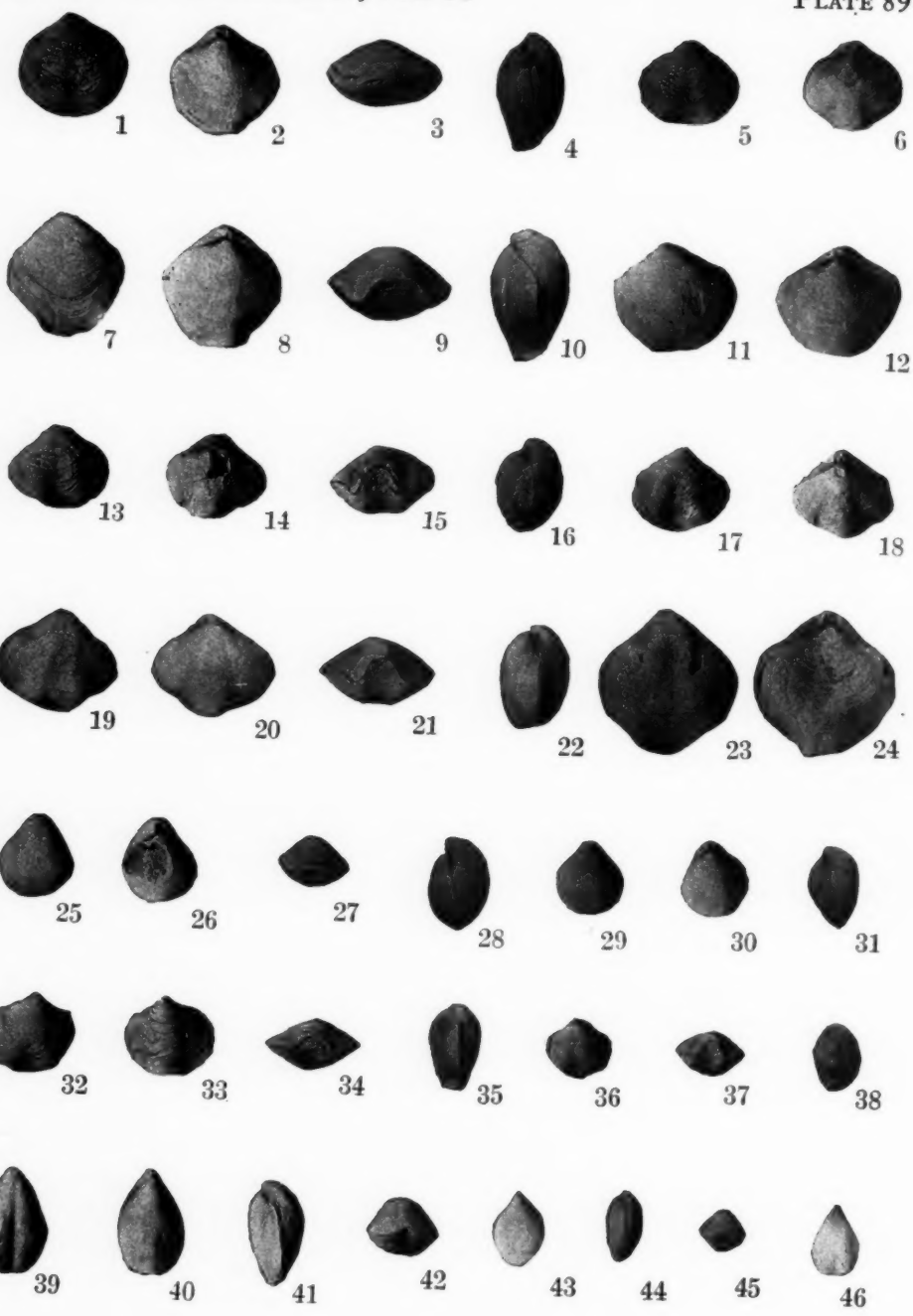
41, 42—Crania sheldoni White. Brachial views of two hypotypes, M.A.S. 39, Buffalo, and S.U.I. 6-507, Iowa City, Iowa. (p. 609)

43, 45, 46—Lingulodiscina marginalis (Whitfield). *43*, Brachial view of a hypotype, S.U.I. 6-505, Muscatine county, Iowa. *45*, Internal views of pedicle valves, S.U.I. 6-506, Iowa City, Iowa. *46*, View of interior of pedicle valve of the largest specimen, *independensis* zone, Waverly, Iowa. (p. 606)

44—Petrocrania? sp. View of the interior of a pedicle valve, M.A.S. 172. (p. 610)



Stainbrook, Devonian Brachiopoda



Stainbrook, Devonian Brachiopoda

Order TELOTREMATA Beecher
Superfamily RHYNCHONELLACEA Schuchert
Family CAMAROTOECHIIDAE Schuchert and LeVene
Subfamily CAMAROTECHIINAE Schuchert and LeVene
Genus CAMAROTOECHIA Hall and Clarke
CAMAROTOECHIA CEDARENSIS Stainbrook, n. sp.

Plate 88, figures 10–15, text figure 2

Shell small, subtriangular in outline, a little wider than long, with the greatest width anterior to the midlength, acutely angular at the beak, the anterolateral margins rounded, the front commissure gently sinuous. Measurements of two paratypes are: length 7 mm., and 8 mm.; width 8 mm. and 9 mm.; thickness 3.5 mm. and 4 mm. Two larger but flattened specimens measure 9.5 mm. and 10 mm. in length and 10.5 mm. and 12 mm. in width.

Pedicle valve convex in the umbonal region, the surface sloping with moderate rapidity to the posterolateral margins and gently to the anterolateral margins; depressed anteriorly by a broad, shallow median sinus, gently concave at the bottom and having its origin on the umbo. Plications strong, angular at their summits, extending from the front and lateral margins to the beak, numbering from three to five in the sinus and from six to eight on each lateral slope, where they are smaller and crowded posteriorly. Internally in the rostral portion of the valve are two strong dental lamellae, which extend a short way toward the front.

Brachial valve a little more convex than the pedicle, most convex toward the front, sloping thence gently at first, then rapidly to the beak and the posterolateral margins. Fold low, originating on the umbo, increasing rapidly in width toward the front, gently convex and rounded at the sides. Plications similar to those of the opposite valve, four or five occupying the fold and five to seven on each slope. Internally the stout median septum reaches nearly to the midlength and supports for a short distance the U-shaped hingeplate. From the latter two stout divergent crura extend to the center of the shell.

Camarotoechia cedarensis differs from *Camarotoechia saxatilis* of the Cerro Gordo shale in its smaller size, in its more distinct fold and sinus, and in the fewer plications on the fold and in the sinus. It is smaller than *Camarotoechia gregeri*, less convex, and tends to have more plications. It is smaller than *Camarotoechia scitulus* and has fewer plications. *Camarotoechia cedarensis* is not so flat as *Camarotoechia depressa*, is more convex toward the front instead of in the umbonal region, and the fold and sinus are both well developed in mature shells.

EXPLANATION OF PLATE 89

FIGS. *1–6—Athyris vittata* var. *randalia* Stainbrook, n. var. *1–4*, Pedicle, brachial, anterior and lateral views of the holotype, M.A.S. 276 A. *5, 6*, Pedicle and brachial views of a paratype, M.A.S. 276. Both from Randalia, Iowa. (p. 616)

7–12—Athyris vittata var. *buffaloensis* Stainbrook, n. var. *7–10*, Pedicle, brachial, anterior and lateral views of paratype S.U.I. 6-232. *11–12*, Pedicle and brachial views of a paratype. Both from Buffalo, Iowa. (p. 616)

13–18—Athyris vittata var. *brandonensis* Stainbrook, n. var. *13–16*, Pedicle, brachial, anterior and lateral views of the holotype, M.A.S. 131A. *17, 18*, Pedicle and brachial views of a paratype, M.A.S. 161. Both from Brandon, Iowa. (p. 616)

19–22—Athyris vittata Hall. Pedicle, brachial, anterior and lateral views of a hypotype. Iowa City, Iowa; type locality. (p. 616)

23, 24—Athyris nettlerothi Stainbrook, n. sp. Pedicle and brachial views of the holotype from the Jeffersonville limestone, Jeffersonville, Indiana. (p. 617)

25–31—Athyris cedarensis Stainbrook, n. sp. *25–28*, Pedicle, brachial, anterior and lateral views of the holotype, M.A.S. 133. *29–31*, Pedicle, brachial and lateral views of a paratype, M.A.S. 276. Brandon and La Porte City, Iowa. (p. 618)

32–38—Athyris zonulata Stainbrook, n. sp. *32–35*, Pedicle, brachial, anterior and lateral views of the holotype, M.A.S. 371A. *36–38*, Pedicle, anterior and lateral views of a paratype, M.A.S. 195. Both from Independence, Iowa. (p. 617)

39–42—Charionella? nortoni Stainbrook, n. sp. Pedicle, brachial, lateral and anterior views of the holotype, M.A.S. 302. Linn Junction, Iowa. (p. 619)

43–46—Meristella parva Cooper and Cloud. Brachial, lateral, anterior and pedicle views of a hypotype, M.A.S. 1285. Linn Junction, Iowa. (p. 618)

Occurrence.—Cedar Valley limestone, in the *waterlooensis* zone at Littleton, Brandon, Iowa City, and Randalia, Iowa. Also occurs in a zonule in middle of the Coralville member in vicinity of Brandon.

Type.—Holotype, S.U.I. 6-313A. Paratypes, S.U.I. 6-313, 6-428, 6-312 and M.A.S. 64 and 52.

Genus HYPOTHYRIDINA Buchman
HYPOTHYRIDINA INTERMEDIA (Barris)
Plate 88, figures 5–7; text figure 5

Rhynchonella intermedia BARRIS, *1878*, Davenport Acad. Sci. Proc., vol. 2, p. 285, pl. 11, figs. 5, 6.
Hypothyris intermedia, HALL and CLARKE, *1893*, Paleontology New York, vol. 8, pt. 2, p. 200.
Rhynchonella emmonsi WALCOTT, *1884*, U. S. Geol. Survey Mon. 8, p. 157.
Hypothyris emmonsi, SCHUCHERT, *1897*, *idem*, Bull. 87, p. 233.

Shell small, subcuboidal in shape, subpentagonal in outline, wider than long, the greatest width at the midlength, posterolateral margins slightly concave and making an obtuse angle at the beak, the lateral margins curved, anterolateral margins broadly rounded, and front margin nearly straight. Dimensions of three specimens are: length 16.7 mm., 17.3 mm., and 16 mm.; width 18.1 mm., 19.6 mm., and 18 mm.; thickness 13.6 mm., 14.3 mm. and 8.9 mm.

Pedicle valve gently convex for the greater part, highest at a point posterior to the midlength, from which the surface curves with moderate rapidity to the lateral margins and more strongly to the hinge line. Sinus originating near the midlength, broad, very shallow, gently convex at the bottom, poorly defined at the sides except toward the front; the anterior portion produced into a long, quadrate, gently curved linguiform extension, which is deflected at right angles to the plane of the valve and may be slightly recumbent in some specimens. Umbo prominent and broadly convex; beak small, pointed, projecting and incurving over and beyond the opposite beak, concealing the pedicle opening. Internally there are two short slightly divergent dental lamellae confined to the rostral portion of the valve.

Brachial valve strongly convex, gently and evenly curved along the fold, more strongly arched transversely, shortened along the midline, truncated at the front by the lingual extension of the opposite valve. Mesial fold broad, low, gently convex at the summit, originating on the umbo, widening rapidly toward the front, defined at the sides by flexures of moderate strength. Lateral slopes strongly and then abruptly deflected from the fold to the margins. Umbonal region gently convex; beak small, a little incurved, concealed by the beak of the pedicle valve. Internal sections reveal no structures in the rostral portion of the valve other than low short ridges or shallow furrows.

The surface of both valves marked by many low, narrow, slightly rounded plications, which extend from the umbo to the front and lateral margins. The number of plications is variable; in the best-preserved specimen at hand there are 10 in the sinus, 11 on the fold, and approximately 17 on each slope; a smaller individual has only 6 in the sinus. Concentric growth striae numerous, occasionally strong enough to be reflected on the interior of the valves. The shell is very thin, scales easily, has a silky luster, and, where preserved, shows the "herring-bone" markings on the plications near the front margin.

Walcott referred *Rhynchonella intermedia* Barris to *Rhynchonella emmonsi* Hall and Whitfield, stating that the differences noted by Barris were insufficient bases for separation. He remarked that these forms and *Rhynchonella venustula* Hall were undoubtedly varieties of *Rhynchonella cuboides* Sowerby. Comparison of examples of Iowa *Hypothyridina* with *Hypothyridina cuboides* from the Rhine Devonian shows that they are not the same.

Study and comparison of a number of examples of *Hypothyridina intermedia* (Barris) with recent illustrations of *Hypothyridina emmonsi* (Merriam, 1941, pl. 9) cause us to reject Walcott's combination of these forms. The features mentioned by Barris are a ready means of separation. They are: smaller size, less ventricose aspect, finer character of the plications, fewer plications on the sides and in the mesial sinus. Also the linguiform extension of the pedicle valve is not as elongate nor so recumbent. The plications are more rounded in our form.

Hypothyridina intermedia has more resemblance to *Hypothyridina* sp. *a* of Mer-

riam (1941, pl. 9) than it does to *Hypothyridina emmonsi*. In the *profunda* zone of the Cedar Valley occurs a *Hypothyridina* nearly twice as large as *Hypothyridina intermedia* and hence more like *Hypothyridina emmonsi*. Possibly Walcott had a specimen of this form at hand. Although similar to *H. emmonsi* in many respects close study shows that it is not the same. In the Independence shale below the Cedar Valley is a *Hypothyridina* indistinguishable from *H. emmonsi*, and it has been referred to this species.

Occurrence.—Cedar Valley limestone in the lower and middle portions of the *independensis* beds. Examples have been collected at Davenport, Solon, Fayette, Alice, and Paris, Iowa.

Types.—The holotype is in the museum of the Davenport Academy of Natural Sciences. Hypotypes, M.A.S. 790, 791 and 793.

HYPOTHYRIDINA INTERMEDIA var. MAGNIVENTRA Stainbrook, n. var.
Plate 88, figures 1–4

Shell of medium size, gibbous, wider than long, broadest at the midlength or slightly anterior, subheptagonal in outline, with nearly straight front margin, broadly rounded lateral margins, and slightly concave posterolateral margins. Anterior commissure strongly sinuous. Measurements of the holotype and of a paratype are: length 22.1 mm. and 21.2 mm.; height 24.3 mm. and 23.5 mm.; thickness 20.1 mm. and 19.7 mm.

Pedicle valve moderately convex, highest a little in front of the umbo, whence the surface slopes with decreasing rapidity to the lateral margins. Sinus broad, very shallow, gently convex at the bottom and originating well up on the umbo; lingual extension broad, high and a little retrorse. Lateral slopes slightly or not at all concave near the margins. Umbo of moderate size, elevated; beak strong, incurving, and pierced by a small elongate foramen. Two short septa are visible on the interior.

Brachial valve strongly convex, strongly and evenly arched from beak to front, highest a little posterior to the front margin. Lateral slopes nearly vertical. Fold broad, low, gently convex to nearly flat, originating at the beak. Umbo broadly convex; beak small, concealed by that of the opposite valve.

Plications low, flat-topped or gently rounded, separated by grooves less than half as wide, numbering about 14 on the fold and in the sinus of mature individuals, and about 26 on each slope. Another example has only 9 plications on the fold. The plications on the internal molds, excepting on the fold, show a slight median groove on each. Where the shell is preserved on the plications it shows minute herring-bone markings. Growth lines occasionally strongly developed so as to be impressed on the internal mold.

Hypothyridina intermedia var. *magniventra* differs from the typical *Hypothyridina intermedia* in that it is much larger and proportionately more convex. The plications are more numerous, flatter, and smaller in proportion to the size of the shell. This variety is about as large as *Hypothyridina emmonsi* (Hall and Whitfield) but differs in several respects. It is longer proportionately, has a more convex pedicle valve, which is not concave near the lateral margins, and its plications are slightly larger. The lingual extension of *Hypothyridina emmonsi* is higher proportionately and retrorse. *Hypothyridina intermedia* var. *magniventra* is as large as *Hypothyridina venustula* but is broader proportionately and has more numerous and smaller plications.

Occurrence.—Cedar Valley limestone in the *profunda* zone at Solon and Paris, Iowa.

Types.—Holotype, M.A.S. 794; paratype, S.U.I. 6-129 and M.A.S. 792.

Family CAMEROPHORIIDAE
Subfamily CAMEROPHORIINAE Waagen
Genus CAMEROPHORIA King
CAMEROPHORIA SUBOVATA (Savage)
Plate 88, figures 29–35

Pugnoides subovata SAVAGE, *1921*, Illinois State Acad. Sci. Trans., vol. 14, pp. 6–7, pl. 2, figs. 5–7.

Shell small, subpentagonal in outline with the posterolateral margins curved and meeting in an acute angle at the beak, a little wider than long, broadest anterior to the midlength, strongly sinuate along the front

commissure. Measurements of two hypotypes are: length 8.5 mm. and 8.3 mm. (incomplete); width 9.1 mm. and 9.7 mm.; thickness 7.6 mm. and 7.1 mm.

Pedicle valve moderately convex, with the greatest convexity anterior to the midlength, its surface flattened or gently convex centrally and abruptly curved beyond to the posterior and lateral margins. Umbonal region slightly elevated and a little projecting. Beak prominent, sharply pointed, a little incurved, and extended over and beyond the opposite beak. Sinus originating near the midlength, extremely shallow, broad, indistinctly defined at the sides, and with the bottom continued at the front to form a quadrate linguiform extension deflected at right angles to the plane of the valve. Internally the dental lamellae are short and confined to the rostral portion of the valve. Between them is a broadly concave spondylium, which extends to the midlength; posteriorly, on either side, it is supported by the bases of the lamellae and throughout its length by the median septum.

Brachial valve a little more convex than the pedicle, highest toward the front, whence the surface curves strongly to the beak and abruptly to the anterior and lateral margins; transversely the central portion is flattened or gently convex. Lateral slopes flat and at right angles to the plane of the valve. Fold broad, low, flattened, originating at the beak, poorly defined at the sides by furrows, which deepen toward the front; anterior portion strongly deflected toward the margin. Internally the hinge plate is short and gives rise anteriorly to two short crura. Beneath it the high median septum extends nearly to the midlength and bears throughout its length a V-shaped cruralium, which becomes wider and more elevated toward the front.

The posterior part of the shell is smooth; the anterior part is marked by low, faint, narrow, gently convex plications, of which four or five are found in the sinus or on the fold, and two or three similar but shorter and less pronounced occupy each slope. Growth striae concentric, numerous, crowded near the front.

The specimens on which the above description is based were sent to Professor Savage for comparison with the holotype of *Pugnoides subovata* and were pronounced by him to be identical. They are from the same horizon but from a different locality. Internal characters revealed by serial sectioning of the rostral portion of the shell show that it must be referred to the genus *Camerophoria*.

Occurrence.—Cedar Valley limestone in the *Cranaena iowensis* zone at Iowa City, Robert's Ferry, Lost Creek in Johnson County, Iowa; Andalusia in Rock Island County, Ill.

Types.—Holotype, Museum, Department of Geology, University of Illinois. Hypotypes, S.U.I. 6-315 and 6-224; M.A.S. 136.

CAMEROPHORIA SWALLOVI (Branson)

Plate 88, figures 22–28; text figure 1

Pugnoides swallovi BRANSON, *1923*, Missouri Bur. Geology and Mines, ser. 2, vol. 17, p. 92, pl. 26, figs. 13–15.

Camerophoria swallovi, BELANSKI, *1928*, Iowa Univ. Studies, vol. 12, no. 7, pp. 25–27, fig. 12, pl. 4, figs. 1–5.

Shell small, subtriangular in outline, subequally biconvex, width and length equal or nearly so, the greatest width anterior to the midlength, lateral margins curved and meeting posteriorly in an acute angle. Dimensions of three hypotypes are: length 7 mm., 6 mm., and 8.9 mm.; width 7 mm., 6.5 mm., and 9.1 mm.; thickness 5 mm., 3.5 mm., and 8.1 mm.

Pedicle valve moderately convex, slightly elevated and a little elongated in the umbonal region, gently convex in the central portion, whence the surface is abruptly deflected to the lateral margins of the valve; anterior median portion continued beneath the sinus in a short quadrate linguiform extension, which is curved and at right angles to the plane of the valve; sinus originating at the midlength, shallow, broad at the anterior margin and occupied by three rounded simple plications extending posteriorly nearly to the middle of the valve. Each lateral slope is marked by three or four shorter plications, the one on either side of the sinus being more pronounced than any on the shell. Beak prominent, sharply pointed, a little incurving, and extending over and beyond that of the brachial valve. Sections of the interior show that the dental lamellae are united and continued

forward to form a trough-shaped spondylium resting on the long median septum in the middle part of the valve.

Brachial valve gently convex, scarcely elevated in the umbonal region, the surface flattened in the central portion but abruptly inflected near the anterior and lateral margins to the pedicle valve; fold originating at the midlength, a little elevated above the remainder of the valve, broad, low, and indistinctly defined except anteriorly by narrow furrows, which are deeper at the front; on the fold are three or four rounded plications extending posteriorly halfway to the beak; on each lateral slope are two or three shorter and similar plications. Internally the hinge plate is continuous and is supported a short way anteriorly by a median septum. Below the hinge plate a concave cruralium, supported by the median septum, is continued beyond the hinge plate to the middle of the shell.

The species is similar to *Camerophoria subovata* but differs in that it is thinner, has more pronounced plications, and slightly more elevated fold and sinus. *Camerophoria subovata* is more subpentagonal than subtriangular and usually has one more plication in the sinus or on the fold.

Occurrence.—Cedar Valley limestone, in the *profunda* beds at Linn Junction, Brandon, Jesup, and Vinton in Iowa. Mineola limestone of Ralls and Montgomery Counties in Missouri.

Types.—Holotype, Museum of the University of Missouri. Hypotypes, S.U.I. 6–321 and 6–671; M.A.S. 84 and 1280.

CAMEROPHORIA GREGERI (Branson)
Plate 88, figures 16–21; text figure 6

Hypothyris gregeri BRANSON, *1923*, Missouri Bur. Geology and Mines, ser. 2, vol. 17, pp. 91–92, pl. 17, figs. 5–7, 11–14.

Shell small, strongly but unequally biconvex, subglobose in shape, subovate in outline, with the front and lateral margins curved, wider than long, with the greatest width toward the front. Dimensions of a hypotype are: length 11 mm.; width 11.5 mm., thickness 10.1 mm.

Pedicle valve less convex than brachial, strongly arched along the midline, gently arched from side to side; sinus nearly obsolete, very shallow, originating near the midlength, gently convex along the bottom, indistinctly defined at the sides by furrows, which increase in strength toward the front, produced anteriorly into a broad, curved, subquadrate, linguiform extension, which is deflected at right angles to the plane of the valve. Plications in the sinus low, narrow, gently convex, and from four to five in number. Lateral slopes marked by five or six similar, wider and shorter plications, which decrease in size and length away from the sinus. Umbonal region slightly convex; beak small, pointed, a little incurving and projecting. Internally there is a median septum extending forward nearly to the midlength. A broken specimen further discloses a V-shaped trough supported by the septum.

Brachial valve highly convex, with the greatest curvature anterior to the midlength, the surface gently convex in the central portion, abruptly arched to the lateral margins, and strongly curved to the beak. Mesial fold nearly obsolete, low, flattened, poorly defined at the sides by shallow, narrow furrows, and bearing from four to six short plications. Lateral slopes deflected from the fold to the margins at right angles to the plane of the valve, marked by five or six plications shorter than those on the fold. Beak small, a little incurved. Internally there can be seen beneath the shell a median septum, which extends anteriorly from the beak nearly to the midlength.

The presence of a median septum in the pedicle valve removes this from the genus *Hypothyridina;* comparison with the sections of *Hypothyridina intermedia* will demonstrate this. A specimen from the Callaway limestone of Missouri has the beak broken away, disclosing in addition to the septum a trough-shaped spondylium. The internal features shown by serial sectioning make reference of this species to the genus *Camerophoria* certain.

Camerophoria gregeri is readily distinguished from *Camerophoria subovata* by its large size, subglobose shape, and fainter fold and sinus.

Occurrence.—Cedar Valley limestone, in the *Cranaena* zone in Muscatine and Scott counties; the Callaway limestone of Missouri.

Types.—Hypotypes, S.U.I. 6–230; M.A.S. 491.

Superfamily ROSTROSPIRACEA Schuchert
Family ATHYRIDAE Phillips
Subfamily ATHYRINAE Waagen
Genus ATHYRIS McCoy
ATHYRIS VITTATA Hall
Plate 89, figures 19–22

Athyris vittata HALL, *1860*, New York State Cab. Nat. History Ann. Rept. 13, pp. 89–90.
Athyris vittata, HALL, *1867*, Paleontology New York, vol. 4, p. 289, pl. 46, figs. 1–4.
Athyris vittata, HALL and CLARK, *1893*, *idem*, vol. 8, pl. 2, p. 90, figs. 62, 63, pl. 45, figs.1–5.
Athyris vittata. BRANSON, *1923*, Missouri Bur. Geology and Mines, ser. 2, vol. 17, p. 110, pl. 17, figs. 8–10, 15, 16.
Athyris fultonensis SCHUCHERT, *1897*, U. S. Geol. Survey Bull. 87, p. 147.
Athyris fultonensis, CLELAND, *1911*, Wisconsin Geol. and Nat. History Survey Bull. 21, pp. 83–84, pl. 14. figs. 1–4.

Shell small, almost equally biconvex, subpentagonal in outline, with broadly rounded cardinal angles and long anterolateral margins, wider than long, with the greatest width near the midlength, strongly sinuate along the front commissure. Dimensions of three hypotypes are: length 15.4 mm.,12.5 mm., and 11.7 mm.; width 16.2 mm., 14.1 mm., and 13.6 mm.; thickness 10.1 mm., 8.3 mm., and 8.2 mm.

Pedicle valve slightly more convex than the brachial, strongly and regularly arched from beak to front along the bottom of the sinus, gently arched transversely; highest in the umbonal region, the surface curving with moderate rapidity to the front and lateral margins and more strongly to the cardinal margin, incurved beneath the beak. Sinus moderately wide, shallow, rounded at the bottom, extending well up on the umbo, bordered at the sides by broadly rounded, low elevations, and continued at the front as a short, rounded linguiform extension. Umbonal region prominent; beak strong, projecting beyond the hinge line, bearing at the apex a large subcircular foramen.

Brachial valve moderately arched from beak to front and from side to side, a little more convex posterior to the midlength. Fold extending to the beak, low, broad, flattened along the summit, and bounded on either side by a broad, short, shallow furrow extending to the umbo. Lateral slopes curving with moderate rapidity from the fold to the lateral margins, and depressed at the front near the fold. Beak short, blunt, concealed by opposite beak.

Exterior of both valves marked by numerous concentric imbricating growth lamellae, which are usually missing from the posterior part of the shell.

Athyris vittata has an extended range in the Cedar Valley and shows considerable variation. In the beds immediately above the coral bed in the *pentamerella* zone at Buffalo occur large numbers of a variety differing from the typical specimens in several respects. It is longer, larger, tends to be proportionately less transverse, and has the fold and sinus less strongly developed and extending only to the umbo. Externally it appears to have less well developed growth lamellae. This variety may be designated as *buffaloensis*. A typical example measures 17.8 mm. in length, 18.5 mm. in width, and 10.1 mm. in thickness. It is illustrated on plate 89, figures 7–12.

Still higher in the *waterlooensis* zone another variety is sparsely represented. It averages much smaller, is proportionately more transverse than the typical form, and has a more sharply folded fold and sinus, which do not extend to the beak. This may be called variety *brandonensis*. A typical example measures 11.8 mm. in length, 13.7 mm. in width, and 9.1 mm. in thickness. Plate 89, figures 13–18.

Another variety occurs in the *Cranaena iowensis* zone abundantly at Randalia and less commonly elsewhere. It is about the same size as the typical form, is more nearly circular, has a less strongly developed fold and sinus, is smoother externally, and has fewer, less prominent, and regularly spaced lamellae. This may be called variety *randalia*. A large example is 15.4 mm. long, 16.2 mm. wide, and 9.6 mm. thick. Plate 89, figures 1–6.

Athyris vittata is generally well represented in the major portion of the Cedar Valley limestone, being absent only from the basal and upper layers. It shows considerable variation in size and shape and in other external features, some of which are probably correlated with the bottom and water conditions about the living animals. Some of these variations are fairly constant and have been recognized above in the descriptions of several varieties. In some zones, examples of the species are sparse, but in others, as the *bellula* zone at Iowa

City and the upper *pentamerella* zone at Buffalo, they may be so abundant as to dominate the fauna locally.

Specimens of *Athyris vittata* from zone C of the Milwaukee formation at Milwaukee, Wis., are very similar to the varieties *brandonensis* and *randalia*. One specimen from Milwaukee is larger than any recovered from the Cedar Valley in Iowa. At Annada, Mo., the variety represented appears to be *randalia*. South of Columbia, Mo., in the Callaway limestone a species of *Athyris* twice as large as *Athyris vittata* has been collected. It may be a new variety or new species of the genus. The common *Athyris* of the Callaway collected along Aux Vasse Creek in company with *Cyrtina missouriensis* (Swallow) is smaller than *A. vittata* and is probably *Athyris fultonensis* (Swallow).

Occurrence.—Cedar Valley limestone. The typical form described by Hall occurs in the *bellula* zone at Iowa City, the type locality, Linder's Boathouse, and elsewhere in Johnson county. The *buffaloensis* variety is from the *Stropheodonta parva* zone at Buffalo, Linwood, and the exposures along the Mississippi in Muscatine county. The *brandonensis* variety occurs in the *waterlooensis* zone at Brandon and Littleton. The *randalia* variety occurs in the *Cranaena iowensis* zone at Randalia, Iowa City, Robert's Ferry, and Linder's Boathouse. Also reported from Rock Island, Ill., from the Milwaukee beds at Milwaukee, Wis.; Mineola limestone of Missouri, and has been collected from the Callaway limestone at Annada, Mo.

Types.—Hypotypes of *Athyris vittata*, S.U.I. 6–299 and 6–232; M.A.S. 61. Holotype and paratypes of variety *buffaloensis*, M.A.S. 162, S.U.I. 6–228, 6–483. Holotype and paratypes of var. *brandonensis*, M.A.S. 131 and 1282. Holotype and paratypes of var. *randalia*, M.A.S. 276.

ATHYRIS NETTLEROTHI Stainbrook, n. sp.
Plate 89, figures 23, 24

Athyris vittata NETTLEROTH, *1889*, Kentucky fossil shells, p. 87, pl. 16, figs. 25–32.
Athyris vittata, SAVAGE, *1931*, Paleontology of Kentucky, pl. 30, figs. 4–5.

In the Jeffersonville and Sellersburg limestone in the vicinity of the Falls of the Ohio occurs a species of *Athyris* which has been assigned in the literature to *Athyris vittata*. There are, however, considerable differences observable when specimens from the Iowa and Indiana localities are compared. The Indiana *Athyris* differs in shape and outline, is nearly twice as large as *A. vittata*, and is slightly longer than wide on the average or as wide. The fold is bordered by less acute furrows on either side, and the anterior commissure is not as strongly sinuous. The shell is thicker proportionately, the umbos are more prominent, and the pedicle beak more protuberant and incurved. A typical example from the Jeffersonville limestone measures 19.5 mm. in length, 19.1 mm. in width, and 13.6 mm. in thickness. In *Athyris vittata* the greatest breadth is at the midlength or a little anterior; in the Indiana *Athyris* the greatest width is posterior. *Athyris vittata* is thickest at the midpoint; the Indiana form is thickest posteriorly. These differences are constant and show that the Jeffersonville and Sellersburg form from the Middle Devonian is a species distinct from *Athyris vittata* Hall. It is proposed here that the form be designated *Athyris nettlerothi*, n. sp.

Types.—Holotype, M.A.S. 1290A from the Jeffersonville limestone at Jeffersonville, Indiana (see pl. 89, figs. 23, 24). Paratypes, M.A.S. 1290 from the Jeffersonville limestone, and 1289 from the Sellersburg limestone, near Jeffersonville, Indiana.

ATHYRIS ZONULATA Stainbrook, n. sp.
Plate 89, figures 32–38

Shell small, transversely subelliptical, subequally biconvex, wider than long, broadest near the midlength, strongly sinuous along the front commissure. Measurements of the holotype and of a paratype are: length 11.5 mm. and 9.5 mm.; width 12.3 mm. and 10.3 mm.; thickness 6.4 mm. and 6.2 mm.

Pedicle valve most convex in the umbonal region, the surface sloping thence with moderate rapidity laterally and anteriorly, flattened a little near the lateral margins. Sinus confined to the anterior half of the valve, broad, shallow, indistinctly defined at the sides by short, broad folds, and with the bottom distinctly rounded and continued at the front to form a linguiform extension more or less sharply curved toward the opposite valve. Beak short, a little incurved and projecting, bearing a circular foramen.

Brachial valve broadly convex in the umbonal region, flattened or depressed near the lateral margins, moderately arched transversely. Fold short, broad, low, limited at either side by a sharply depressed furrow. Beak blunt, projecting slightly. Surface of both valves marked by numerous projecting, concentric growth laminae.

Athyris zonulata is smaller than *Athyris vittata*, it is proportionately wider, less gibbous, and has the fold and sinus confined to the anterior part of the shell. The transversity of the shell distinguishes it readily from *Athyris cedarensis*.

Occurrence.—Cedar Valley limestone in the *independensis* zone at Independence, Linn Junction, and Cedar Rapids.

Types.—Holotype, M.A.S. 195; paratypes, M.A.S. 197, 249, 371, and 1284.

ATHYRIS CEDARENSIS Stainbrook, n. sp.
Plate 89, figures 25–31

Shell small, subtriangular in outline, unequally biconvex, thickest posterior to the middle, longer than wide, with the greatest width anterior to the midlength, slightly sinuate along the front commissure. Dimensions of the holotype and of a paratype: length 11.4 mm. and 10 mm.; width 10.5 mm. and 9.3 mm.; thickness 7.6 mm. and 6.4 mm.

Pedicle valve strongly arched, with the greatest curvature posterior to the midlength, broadly arched transversely, flattened along the midline. Sinus broad, shallow, indistinctly defined at the sides, extending to the umbo and with the bottom slightly extended at the front. Lateral slopes curving strongly from the borders of the sinus to the lateral margins, much incurved beneath the beak. Umbonal region prominent, narrow, greatly projecting beyond the hinge line. Beak stout, strongly incurved, bearing a large circular apical foramen.

Brachial valve moderately arched longitudinally and transversely, most convex in the umbonal region, the surface curving with moderate rapidity from the midline to the lateral margins, slightly elevated into an indistinct fold at the front margin. Beak strongly projecting, concealed by opposite beak. Both valves marked externally by numerous fine, concentric, sublamellose growth lines.

Athyris cedarensis is smaller than *Athyris vittata*, is longer than wide, has the greatest width anterior to the midlength, has a less pronounced fold and sinus, and less well developed growth laminae.

Several examples were sent to the University of Michigan for comparison with *Athyris eborea* Winchell. Dr. G. M. Ehlers and Miss Virginia Kline write that

> The Cedar Valley species differs in relatively greater length of shell, heavier and more distantly spaced growth lines and apparently more gibbous condition of the pedicle valve in the umbonal region.

Occurrence.—Cedar Valley limestone, upper part of the Coralville member, at Brandon, La Porte City, and Iowa City, Iowa.

Types.—Holotype, M.A.S. 133; paratypes, M.A.S. 276 and 494.

Family MERISTELLIDAE Hall and Clarke
Subfamily MERISTELLINAE Waagen
Genus MERISTELLA Hall
MERISTELLA PARVA Cooper and Cloud
Plate 89, figures 43–46, text figure 3

Meristella parva COOPER and CLOUD, *1938*, Jour. Paleontology, vol. 12, no. 5, p. 451, pl. 54, figs. 40, 46, 47.

Shell small, subequally biconvex, subovate in outline, broadest posterior to the midlength, slightly sinuous along the anterior commissure. A typical example measures 9.6 mm. in length, 7.1 mm. in width, and 5.1 mm. in thickness.

Pedicle valve slightly more convex than the brachial, strongly and regularly arched from beak to front, highest near the midlength or posterior to it. Anterior median portion flexed by a short, indistinct sinus, which indents the opposite valve a little. Brachial valve gently convex, highest in the umbonal region, arching with decreasing curvature toward the front. Fold broad, low, indistinct. Serial sections show short dental lamella in the pedicle valve and a short median septum bearing the cruralium in the brachial valve. Shell is impunctate.

Occurrence.—Cedar Valley limestone in the *profunda* zone at Linn Junction, Iowa. Originally described from Devonian limestone near Kritesville, Illinois.

Types.—Holotype, U. S. Nat. Museum 95181a; paratypes, 95181b-g; hypotypes, M.A.S. 1285.

Genus CHARIONELLA Billings

CHARIONELLA? NORTONI Stainbrook, n. sp.
Plate 89, figures 39–42; text figure 4

Shell small, moderately biconvex, much longer than wide, broadest anterior to the midlength, subcuneate in outline, the posterolateral margins long and meeting in an acute angle at the beak, anterolateral margins rounded, the front margin truncate. Dimensions of the holotype and of a paratype are: length 13.3 mm. and 12.1 mm.; width 8.9 mm. and 8.2 mm.; thickness 7.1 mm. and 6.7 mm.

Pedicle valve longer and more convex than the brachial, moderately arched along the midline, with the curvature progressively greater toward the beak, highest in the umbonal region, the surface curving with moderate rapidity to the anterior margins and abruptly to the sides. Mesial sinus extending from the umbo to the front margin, variable in width and depth, its sides gently convex and meeting sharply at the bottom in an obtuse angle; more or less obsolete in some specimens and more strongly developed in maturer shells. Umbonal region strongly elevated and projecting beyond the hinge line, the sides flattened, nearly vertical, and a little incurved at the margins. Beak strong, narrow, sharply pointed, and extended over and beyond the opposite beak, incurved, bearing a small circular foramen at the apex. Internally there are two short dental lamellae in the rostral portion of the valve.

Brachial valve gently arched from the umbo to the front margin, with the greatest convexity posterior to the midlength, strongly arched transversely, the surface elevated along the midline and strongly curved to the lateral margins. Umbonal region highly elevated, with nearly vertical sides. Beak strong, pointed, extended a little, incurved. Internally in the apical portion of the valve two septa arise near the median line and extend forward for about one-fifth the length of the valve. Posteriorly they support for a short distance the divided hinge plate. The surface of both valves is marked by numerous concentric lines of growth, which occasionally may be strongly developed. The shell substance is impunctate.

This species has been questionably referred to *Charionella* because of its shape, the impunctate nature of the shell, the presence of internal spires, and the strong development of septa in the brachial valve. No specimens of the genotype are at hand for comparison and internal sectioning, and definite conclusions could not at this time be made. *Charionella? nortoni* differs from *Charionella scitula* Hall in its smaller size, proportionately narrower and thicker shell, and its deeper, subangular sinus.

This species occurs with *Meristella parva* Cooper and Cloud and resembles it in some respects. It is larger, however, more elongate, has the greatest width anterior to the midpoint, and has long septa in the brachial valve. *Meristella parva* has a single septum supporting the cruralium.

Occurrence.—Cedar Valley limestone in the *profunda* zone at Linn Junction, Vinton, Brandon, and Troy Mills, Iowa.

Types.—Holotype, M.A.S. 302; paratypes M.A.S. 303.

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NEW GENERA OF ORDOVICIAN BRACHIOPODS

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ABSTRACT—Six new genera of Ordovician brachiopods and their genotypes are described. The specimens were taken from post-Canadian and pre-Trenton rocks. The new genera are: *Campylorthis*, *Fascifera*, *Bimuria*, *Dactylogonia*, *Ancistrorhyncha* and *Rostricellula*.

THIS PAPER describes six new genera of Ordovician brachiopods occurring in post-Canadian and pre-Trenton rocks of the Southern Appalachian region. These genera have proved to be important horizon markers and are easily identified. They have been abstracted from a forthcoming manuscript on "Chazyan and related Brachiopods" by the authors and are prepublished in order to make them available for use in the new edition of "North American Index Fossils" by Drs. H. W. Shimer and R. R. Shrock. Acknowledgment is here gratefully made to the Geological Society of America for assistance in preparing and photographing the fossils through a grant from the Penrose Bequest.

Genus FASCIFERA Ulrich and Cooper, n. gen.

Usually small, subcircular in outline, nearly plano-convex to unequally biconvex, the ventral valve always having the greater depth. Hinge narrower than the greatest shell width; cardinal extremities obtuse. Anterior commissure sulcate to rectimarginate. Exterior costellate to fascicostellate. Shell substance fibrous and endopunctate.

Interior: Like *Pionodema* with flaring dental plates in the ventral valve and a small plate at the apex of the delthyrium. Ventral median ridge only slightly developed. In the dorsal valve the brachiophores are long and thin, with discrete supporting plates converging slightly dorsally and uniting with the floor of the valve on each side of the median ridge. Cardinal process long and thin with a narrow, crenulate myophore. Shell substance endopunctate.

Genotype, *Fascifera subcarinata* Ulrich and Cooper, n. sp.

Discussion.—The general dalmanelloid outline and profile combined with the internal features of *Pionodema* distinguish the species of this genus from other punctate shells. Most species show a fair degree of fasciculation of the costellae—a feature that generally distinguishes it from *Pionodema*. Like the latter *Fascifera* also has the swollen, hollow costellae that are a constant feature of the Schizophoriidae. These hollow ribs are developed in varying degree among the species, some having many while others have few. They also complicate identification because their development in the same species is not uniform.

Internally few variations between *Fascifera* and *Pionodema* occur. In the ventral valve the median ridge anterior to the adductor field is not as well developed in the specimens of *Fascifera* studied as it is in *Pionodema*. In the dorsal valve of *Pionodema* the cardinal process is often elevated within the notothyrial cavity on a swelling of shell material—a feature that has not been observed in *Fascifera*.

Species of *Fascifera* occur in the Ottosee formation in the Appalachians and in the Lebanon, Ridley and Pierce formations of the Central Basin of Tennessee. The *Dalmanella hamburgensis* Winchell and Schuchert (not Walcott) from the upper Decorah shale of Minnesota belongs to this genus, and another new species is known from the Trenton in the Southern Appalachians. *Dalmanella stonensis* (Safford) from the Ridley is also referred here.

FASCIFERA SUBCARINATA Ulrich and Cooper, n. sp.
Plate 90, figures 1–5

Shell small, nearly circular in outline, with rounded lateral and anterior margins. Hinge narrower than the greatest shell width, which is near the middle. Cardinal extremities obtusely rounded. Surface cos-

tellate, costellae appearing in four generations and somewhat fasciculate near the margins. Four costellae occupy 1 mm. at the front margin.

Ventral valve gently and evenly convex in lateral profile, with elevated and slightly incurved beak. Anterior profile subcarinate, with moderately steep, flattish slopes. Umbonal and median regions subcarinate, the angularity decreasing anteriorly from the middle. Interarea slightly curved, moderately long, apsacline. Delthyrium open except for a short plate at the apex. Interior with well-developed divergent dental plates defining shallow umbonal cavities. Diductor scars elongate, adductor field moderately wide. Vascular media short, usually indistinct, divergent.

Dorsal valve more convex than the ventral valve in lateral profile; anterior profile broadly but gently convex; umbo gently convex; sulcus originating just anterior to the umbo, narrowly U-shaped in section, widening very slightly anteriorly and extending to the anterior margin. Interarea short, anacline. Brachiophores moderately long, acute, supported by thin plates that converge to the floor of the valve on each side of the median ridge. Notothyrial cavity deep, cardinal process small.

Measurements: Length of ventral valve (U.S.N.M. 108198a) 9.7 mm., width 10.0 mm., hinge width 7.9 mm., thickness 2.5 mm.; dorsal valve (U.S.N.M. 108198e) length 9.6 mm., width 10.6 mm., hinge width 7.7 mm., thickness 2.5 mm.

Holotype: U.S.N.M. 108198e; figured paratypes U.S.N.M. 108198a–d; unfigured paratypes U.S.N.M. 108198f–r.

Horizon and locality.—Lebanon limestone, vicinity of Lone Mountain, near Tazewell, Tennessee.

Discussion.—This species differs from *F. stonensis*, the only other described species of the genus, by its finer ornamentation and more carinate ventral valve.

Genus CAMPYLORTHIS Ulrich and Cooper, n. gen.

Plate 90, figures 6–12

Valcourea (part) SCHUCHERT and COOPER, *1932*, Peabody Mus. Nat. History Mem., vol. 4, pt. 1, p. 97.

Shells wider than long, cardinal extremities varying from alate to obtusely rounded. Lateral profile convexi-concave to unequally biconvex. The dorsal valve is always the deeper of the two. Anterior commissure varying from rectimarginate to uniplicate. Interareas subequal in length, the ventral one generally apsacline; dorsal interarea orthocline to anacline and usually extended posterior of the ventral beak. Surface multicostellate, costellae of unequal size. Impunctate.

Ventral valve with the musculature of *Dinorthis* consisting of elongate anteriorly widening and divergent diductor scars, moderately strong adjustor impressions at the base of the dental plates, and a small adductor field bisected by a low median ridge. Muscular area square to elongate-rectangular in outline. Teeth small, with large fossettes; dental plates short, stout, and receding, defining small umbonal cavities. Pallial markings as in *Dinorthis*. Delthyrium open or covered.

Dorsal cardinalia as in *Dinorthis;* brachiophores short, rodlike, supported by excess shell deposited on their inner surface. Cardinal process with short shaft and narrow crenulate myophore in the young but with swollen and triangular myophore in old specimens. Median ridge short, adductor field small.

Genotype, *Strophomena deflecta* Conrad, *1843*, Acad. Nat. Sci., Philadelphia Proc., vol. 1, p. 332.

Figured specimens: U. S. N. M. 108199a–d.

Discussion.—*Campylorthis* most nearly resembles *Multicostella* and possesses a similar muscular arrangement and pallial marks but differs in the profile of the valves. *Multicostella* is biconvex in lateral profile but *Campylorthis* has the ventral valve concave in the anterior half or two-thirds. In some individuals this concavity is not strongly marked, and differentiation from *Multicostella* is difficult.

The type species of *Campylorthis* has long been assigned to the genus *Valcourea*, and the common presence of a deltidium in the two genera made this similarity striking. Nevertheless, an important difference in the cardinal process of the two may be noted, that of *Valcourea* possessing a high median ridge rising above the surface of the myophore. The cardinal process of *Campy-*

lorthis is marked by no such ridge, and the structure is like that of *Dinorthis*, with a crenulate myophore.

The presence of a deltidium is a feature not common to all species assigned to the genus, and only two species are known to possess a cover. Aside from the absence of a deltidium, the other species are structurally like the type. Species assigned to *Campylorthis* are *Plaesiomys toricula* Hall and Clarke, *P. elongata* Willard, *P. brevis* Willard and *Valcourea magna* Schuchert and Cooper.

Genus BIMURIA Ulrich and Cooper, n. gen.

Shell moderately large, attaining a width of about an inch, semicircular to semielliptical in outline, concavo-convex in profile. Ventral interarea curved, longer than the dorsal one, anacline; dorsal interarea hypercline. Delthyrium in well-preserved individuals partially closed by a short deltidium. Beak perforated by a tiny foramen. Umbonal region generally smooth; more or less of the remaining surface covered by thin, wrinkled shell lamellae. Shell structure fibrous, pseudopunctate.

Ventral interior: Teeth small, rudimentary; dental plates obsolete; diductor and adjustor scars located at the base and sides of the delthyrial cavity; diductor scars large; adductor scars indistinct. Vascula media strong, extending to about the middle of an adult shell, then branching. The inner branches extend nearly to the margin, where they again branch.

Dorsal interior: Brachial processes elongate, slender, widely divergent. Chilidial plates strongly developed, attached to brachial processes and sides of notothyrium by callus. Cardinal process simple, myophore slender or somewhat expanded; shaft short, united with a thin median septum

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EXPLANATION OF PLATE 90

FIGS. *1–5—Fascifera subcarinata* Ulrich and Cooper, n. sp. *1*, Ventral interior, ×2, paratype, U.S.N.M. 108198a. *2, 3*, Respectively ventral and dorsal exteriors, ×2, paratypes U.S.N.M. 108198b, c. *4, 5*, Dorsal interior, ×2, paratype and holotype U.S.N.M. 108198d, e. Specimen shown by *4* is tilted to show brachiophore supporting plates. Lebanon limestone, vicinity of Lone Mountain, near Tazewell, Tenn. (page 620)

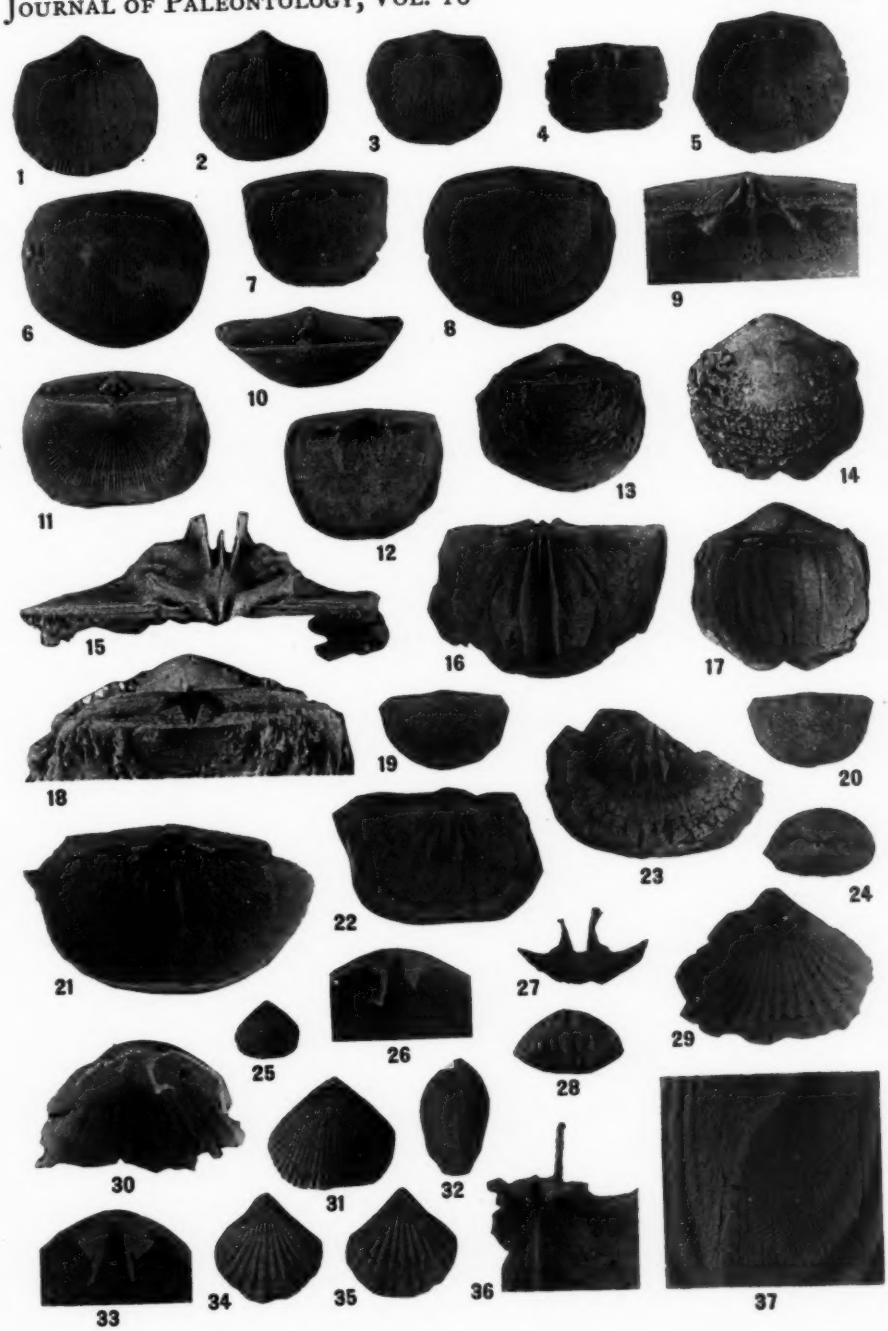
6–12—Campylorthis deflecta (Conrad). *6, 8*, Respectively dorsal and ventral exteriors, ×1, figured specimen U.S.N.M. 108199a. *9*, Enlargement of the dorsal cardinalia, ×2, figured specimen U. S. N. M. 108199d. *10, 11*, Two views showing interareas, deltidium and chilidium, ×1, of the same specimen. *7, 12*, Dorsal and ventral interiors respectively, ×1, figured specimens U.S.N.M. 108199b, c. Plattin limestone, on the old road 1 mile northwest of the Chicago Summer School Camp, NW. ¼ NW. ¼ sec. 32, T. 37 N., R. 9 E., Ste. Genevieve County, Mo. (p. 621)

13–18—Bimuria superba Ulrich and Cooper, n. sp. *13*, Dorsal exterior, showing wrinkled lamellae, ×1, holotype, U. S. N. M. 108200a. *18*, Enlargement of interareas, showing ventral foramen, chilidial plates, and simple cardinal process of the holotype, ×2. *16*, Dorsal interior, showing septa, ×2, paratype U.S.N.M. 108200b. *15*, Posterior view of dorsal interior, showing cardinalia and septa of same specimen, ×3. Strasburg (upper Lenoir) limestone, southeast edge of Friendsville, Tenn. *14, 17*, Exterior and interior of a ventral valve, ×1, paratype U.S.N.M. 108201. Strasburg (upper Lenoir) limestone, 1 mile southeast of Fowlers Mill, 10 miles southeast of Loudon, Tenn. (p. 623)

19–23—Dactylogonia geniculata Ulrich and Cooper, n. sp. *19, 20*, Dorsal and ventral exteriors, ×1, holotype U.S.N.M. 108202a. *21*, Ventral interior, ×2, paratype U.S.N.M. 108202b. *22, 23*, Two dorsal interiors showing bladelike plates, ×2, paratypes, 108202c, d. Strasburg (upper Lenoir) limestone, southeast edge of Friendsville, Tenn. (p. 624)

25–27, 30. 31—Ancistrorhyncha costata Ulrich and Cooper, n. sp. *25, 31*, Dorsal view, ×1 and ×2, of the holotype U.S.N.M. 108203. *26, 27, 30*, Dorsal interiors, ×3, showing divided hinge plate and crura with hooklike extension, paratypes U.S.N.M. 108204c, d. g. Ridley limestone, 1½ miles southeast of Hembree Mill, Sequatchie Valley, Bledsoe County, Tenn. (page 625)

24, 28, 29, 32–37—Rostricellula rostrata Ulrich and Cooper, n. sp. *24, 28, 32, 34, 35*, Respectively posterior, anterior, lateral, dorsal, and ventral views of the holotype, ×1, U.S.N.M. 108205a. *29*, Interior of the ventral valve showing dental plates, ×2, paratype U.S.N.M. 108205h. *33, 36*, respectively showing the hinge plate from the posterior side and the ventral view exhibiting the cruralium and long crus, ×4, paratypes U.S.N.M. 108205g, d. *37*, The fine ornamentation of the exterior, ×6, paratype U.S.N.M. 108205b. Lebanon formation, 7 miles southwest of Clinton, Tenn. (p. 626)



Ulrich and Cooper, Ordovician Brachiopods

that extends for nearly the full length of the valve and is located between two slightly divergent lateral septa. Lateral septa high and thin in the young, overgrown and nearly obliterated in old shells by callus deposited on their inner and outer sides. Adductor impressions somewhat flabellate, located on the posterior portion of the callus deposits on the outside of the lateral septa.

Genotype, *Bimuria superba* Ulrich and Cooper, n. sp.

Discussion.—Species of this genus have been assigned to *Plectambonites* (*Sowerbyella*) and *Christiania*. From the *Sowerbyella* it differs by its exterior and the presence of the longitudinal lamellae inside the dorsal valve. No taxonomic relationship exists between *Bimuria* and *Plectambonites* as recently restricted. *Bimuria* resembles *Christiania* in external form but is never so elongated as species of that genus. The dorsal interior of *Bimuria* differs from that of *Christiania* in the possession of a simple cardinal process rather than a rafinesquinoid, bilobed cardinal process as is present in *Christiania*.

Besides the type, a species of *Bimuria* is abundant in the Little Oak limestone of Alabama and a described species, *Christiania lamellosa* Bassler, is abundant in the upper part of the Chambersburg limestone of Virginia, Maryland and Pennsylvania. *Plectambonites? youngiana* (Davidson) from the Stinchar limestone of Girvan, Scotland, is referred to *Bimuria*.

BIMURIA SUPERBA Ulrich and Cooper, n. sp.
Plate 90, figures 13–18

Shell large, subcircular in outline, varying from slightly wider than long to slightly longer than wide; cardinal extremities varying from a right angle to a slightly obtuse angle. Lateral margins nearly straight to gently convex; anterior margin broadly rounded. Profile concavo-convex, with the ventral valve strongly convex and its beak overhanging the dorsal interarea. Surface generally nearly completely covered by fine wrinkled, crowded, concentric lamellae.

Ventral valve strongly convex in lateral profile, and with the greatest convexity near the middle. Umbo strongly swollen. Anterior profile strongly convex. Lateral and anterior slopes abrupt and steep. Posterolateral slopes steep and slightly concave. Interarea strongly concave, anacline.

Dorsal valve deeply concave, with the greatest concavity near the midregion. Interarea strongly hypercline. Umbonal region deeply concave.

Measurements: Length of holotype 19.7 mm., width 22.2 mm., hinge width 18.4 mm., thickness 8.5 mm.

Holotype: U.S.N.M. 108200a; figured paratypes U.S.N.M. 108200b, 108201; unfigured paratypes U.S.N.M. 108200c–j.

Horizon and locality.—Strasburg formation (upper Lenoir of older reports), southeast edge of Friendsville; one mile southeast of Fowlers Mill, 10 miles southeast of Loudon; both in Blount County, Tennessee.

Discussion.—This species differs from *B. lamellosa* Bassler by its much larger size and less rounded lateral margins.

Genus DACTYLOGONIA Ulrich and Cooper, n. gen.

Shell of moderate size, often attaining slightly more than an inch in width, usually wider than long, with the hinge forming the widest part; lateral margins sloping inward, anterior margin broadly rounded. Concavo-convex in lateral profile, with both valves geniculated strongly in a dorsal direction. Surface finely costellate, usually without concentric wrinkles. Shell substance fibrous, pseudopunctate.

Ventral valve with long palintrope, covered delthyrium, strongly convex deltidium, and small apical foramen. Muscular field moderately large, with fairly long and wide diductor scars, adjustor impressions present, and adductors attached to a low median elevation. Internal surface tuberculate.

Dorsal valve with small cardinal process composed of two short-shafted pieces, with myophore surfaces each receiving a pair of muscles. Median ridge low or obsolete. Brachial processes flat blades supported by callous swelling of the notothyrial and muscular regions. Adductor field fairly small, marked by four bladelike plates arising from the floor, the smaller two between the anterior and posterior adductor scars, and the larger two on the inside of the anterior scars. Line of geniculation marked by a low, thickened ridge. Entire inner surface tuberculate.

Genotype, *Dactylogonia geniculata* Ulrich and Cooper, n. sp.

Discussion.—*Dactylogonia* differs from *Leptaena* in the absence of concentric wrinkles in the visceral portion, but more importantly in the presence in the dorsal valve of the bladelike ridges arising from the floor between the muscular scars and in the small median ridge. Members of this genus occur in the Chazy (Crown Point and Valcour limestones) of New York and in the Lenoir and Strasburg limestones of the southern Appalachians of Tennessee. *Leptaena incrassata* Hall is referred to this genus.

DACTYLOGONIA GENICULATA Ulrich and Cooper, n. sp.
Plate 90, figures 19–23

Shells wider than long with acute cardinal extremities; profile concavo-convex; lateral margins sloping medially, anterior margin broadly convex to subtruncate. Surface covered by closely crowded costellae of unequal size, five to nine of the finer costellae arranged in groups by the scattered larger ones.

Ventral valve with the posterior 9 mm. nearly flat, but the anterior narrowly convex; geniculation takes place about 9 mm. anterior to the beak, and the angle of geniculation is about 95°. The beak is erect, the umbo inconspicuous but slightly swollen. Geniculated part narrowly convex; front slope slightly convex in profile and very steep.

Umbo of dorsal valve forming a round hollow anterior to the beak, body of valve slightly concave but flattened somewhat at the cardinal extremities. Geniculated part fits closely against the dorsally directed portion of the ventral valve and has practically the same contour as that valve.

Interior of ventral valve with muscular field not quite extending to the middle, moderately impressed; adductor ridge low. Dorsal valve with short median septum situated between the lobes of the cardinal process; adductor blades strongly developed; ridge at front of visceral area slightly elevated, moderately thick.

Measurements of holotype: length 11.1 mm., width 15 mm., hinge-width 16 mm. plus, thickness 3 mm., surface length from beak to anterior margin 15 mm.

Holotype: U.S.N.M. 108202a; figured paratypes U.S.N.M. 108202b–d; unfigured paratypes U.S.N.M. 108202e–g.

Horizon and locality.—Strasburg (upper Lenoir) limestone in southeast edge of Friendsville, Tennessee.

Discussion.—This species differs from *D. incrassata* (Hall) in its larger size, flatter ventral visceral area, and more strongly geniculated front.

Genus ANCISTRORHYNCHA Ulrich and Cooper, n. gen.

Protorhyncha (part) HALL and CLARKE, *1894*, Paleontology New York, vol. 8, pt. 2, p. 180.
Protorhyncha (part), RAYMOND, *1911*, Carnegie Mus. Annals, vol. 7, no. 2, p. 226.

Shell small, rhynchonelloid in outline and profile, valves subequal in depth; biconvex in profile; anterior commissure uniplicate. Surface marked by radial costae. Impunctate.

Ventral valve with open delthryium, vestigial interarea, incurved beak. Delthyrial cavity deep, bounded by strong dental plates separated from the inner sides of the valve by deep umbonal cavities; teeth small, curved. Details of musculature unknown.

Dorsal valve with divided hinge plate; sockets deep, defined by a fulcral plate and a thin but elevated socket ridge; outer hinge plate slightly concave; crural base forming inner edge of outer hinge plate; crura long and slender, ending in a broad hooklike expansion (pl. 1, fig. 30) pointing anterolaterally and nearly at right angles to the crus. Musculature unknown; median septum absent.

Genotype, *Ancistrorhyncha costata* Ulrich and Cooper, n. sp.

Discussion.—This genus is characterized by its rhynchonelloid exterior, fine regular costae, open delthyrium, strong dental plates, divided hinge plate and long crura. It is distinguished from *Rhynchotrema* by absence of a dorsal median septum and cruralium, and the fine, even nature of the ornamentation.

Shells of this type had hitherto been placed in the genus *Protorhyncha*, but the continued use of this name seems inadvisable because the specimens on which it was based have been lost, and the proposed neotype is still undescribed. As pointed out

by Raymond, the types of *P. dubia* may be the young of "*Camarotoechia*" *plena*; "*C.*" *pristina*, or an exfoliated *Hebertella*. As the original figures and description are too poor to settle the question, it is better to leave the name *Protorhyncha* and its dubious types unused.

In proposing the name *Protorhyncha*, Hall and Clarke designated *Atrypa dubia* Hall from the Chazy limestone of New York as type, although they derived their description from specimens collected at High Bridge, Kentucky, which they presumably identified with the New York species. These High Bridge specimens were later identified as *Protorhyncha ridleyana* (Safford) by Ulrich and were selected as neotypes for the genus by Raymond when it was discovered that the New York specimens were lost. Although long known to collectors and as museum specimens, *P. ridleyana* was never described, neither by Safford nor by Ulrich, and therefore has no validity as a species. In the interest of stability and clarity we therefore propose a new genus based on well-preserved specimens and leave the uncertain *Protorhyncha* to be reestablished upon discovery of additional material of *P. dubia* from the type locality.

Ancistrorhyncha is known from the Ridley, Pierce, and Lebanon limestones of the Central Basin of Tennessee; Ridley limestone, Sequatchie Valley, Tennessee; from the Ottosee and Lowville of the Southern Appalachians; the Bromide of Oklahoma; and the Plattin and the "Murfreesboro" of Missouri.

ANCISTRORHYNCHA COSTATA Ulrich and Cooper, n. sp.

Plate 90, figures 25–27, 30, 31

Shells small, valves subequal in depth, subtriangular to subpentagonal in outline; beak slightly greater than a right angle; sides straight, diverging from the beak to about the middle, where the shell attains its maximum width; sides rounded at the middle; front margin truncated. Surface marked by low, rounded costae separated by furrows narrower than the costae. The sulcus is marked by 6 to 10 costae, the fold by 7 to 11 costae, and the flanks bear about 13 costae.

Ventral valve moderately convex in lateral profile, with the greatest convexity in the tumid posterior half; sulcus originating near the middle, shallow, with a short narrowly rounded tongue; sulcus occupying about half the width at the front margin. Flanks fairly strongly rounded and with moderately steep slopes.

Dorsal valve moderately convex in lateral profile, and with the maximum curvature near the middle; anterior profile fairly strongly rounded. Umbonal and median regions swollen; fold originating slightly anterior to the middle, low in most specimens and in some scarcely distinguishable. Flanks moderately rounded, and with moderately steep slopes.

Measurements of the holotype: length 7.8 mm., width 8.7 mm., thickness 5.0 mm.

Holotype: U.S.N.M. 108203; figured paratypes U.S.N.M. 108204c, d, g; unfigured paratypes U.S.N.M. 108204a, b, e, f, h–l.

Horizon and locality.—Ridley limestone, 1½ miles southeast of Hembree Mill, Sequatchie Valley, Pikeville special quadrangle, Bledsoe County, Tennessee.

Discussion.—The material on which this species is based consists of fairly well preserved silicified specimens etched from limestone. The specimens preserve the long crura and their hooklike processes, structures that are exceptionally delicate. This species attains about the maximum dimensions seen in the genus. It differs from *A. australis* (Foerste), the only other described species, by its stronger ornamentation, less strongly incurved beak, and less tumid dorsal valve.

Genus ROSTRICELLULA Ulrich and Cooper, n. gen.

Shell rhynchonelliform, generally subtriangular to subpentagonal in outline, more rarely transversely elliptical. Anterior commissure uniplicate. Ventral valve with pointed and generally incurved beak; delthyrium open or partially restricted by rudimentary deltidial plates. Interarea narrow, almost obsolete. Ventral interior with strong dental plates separated from the sides of the valve by narrow umbonal cavities. Teeth small, curved. Delthyrial cavity deep, occupied wholly by the scar of the pedicle attachment; muscular field anterior

to the delthyrial cavity, like *Rhynchotrema* in pattern.

Dorsal interior with divided hinge plate united to median septum by short supporting plates that form a small chamber or cruralium beneath the beak. Brachial processes long and slender, curved. Median septum strong, elevated, reaching the middle of the valve or beyond. Adductor impressions on each side of the septum in the posterior half of the shell.

Genotype, *Rostricellula rostrata* Ulrich and Cooper, n. sp.

Discussion.—This genus differs from *Rhynchotrema* by absence of a cardinal process in the dorsal valve and the lack of lamellose ornamentation.

ROSTRICELLULA ROSTRATA Ulrich and Cooper, n. sp.
Plate 90, figures 24, 28, 29, 32, 37

Shell about medium size for the genus, triangular to subpentagonal in outline; dorsal valve slightly deeper than the ventral; beak forming a right angle; greatest width at or slightly anterior to the middle; anterolateral margins narrowly rounded, front margin broadly rounded. Surface costate, three to five costae occupying the sulcus and four to six defining the fold; flanks marked by six costae. Entire surface covered by fine radial and concentric lines that produce granules where they intersect.

Ventral valve moderately convex, with the greatest convexity from the middle to the umbo. Posterior quarter and umbonal region moderately convex; sulcus originating about 6 mm. anterior of the beak, flat in profile, shallow, and producing a short truncated tongue anteriorly. Sulcus occupies more than half the width at the front. Flanks gently convex, and with moderately steep slopes to the margins.

Dorsal valve evenly and strongly convex in lateral profile and strongly convex in anterior profile; greatest convexity near the middle. Umbonal region swollen. The fold originates about 5 mm. anterior to the dorsal beak; posterior to the fold a shallow and poorly defined sulcus marks the shell. Fold low, spreading gradually anteriorly, gently convex in profile. Flanks moderately convex and with moderately steep slopes to the margins.

Interior: Teeth small, supported by short dental plates separated from the outside wall of the shell by narrow umbonal cavities; scar of pedicle attachment slightly thickened. Dorsal valve with a high and thin median septum supporting a short, shallow and narrow cruralium, which in turn supports a divided hinge plate. Crura long, slender and curved.

Measurements of holotype: Length 14.3 mm., width 14.4 mm., thickness 8.6 mm.; a paratype U.S.N.M. 108205c measures: length 15.3 mm., width 15.3 mm., thickness 9.3 mm.

Holotype: U.S.N.M. 108205a; figured paratypes 108205b, d, g, h; unfigured paratypes U.S.N.M. 108205c, e, f.

Horizon and locality.—Lebanon formation, 7 miles southwest of Clinton, Tennessee.

Discussion.—This is a large species that might be confused with some forms of *R. plena* (Hall). It differs from that species, however, in having less numerous costae in the sulcus and on the fold, in being smaller, and in having a more rotund outline.

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COMMENTS ON THE ORIGIN AND GENERIC STATUS OF EQUUS

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ABSTRACT—Most American and many foreign paleontologists hold that *Equus* is the descendant of a line carrying back through *Pliohippus* to the protohippine species of *Merychippus*. On the other hand, some authorities contend that at least some of the species of *Equus* descended from *Hipparion*.

A careful review of the characters which have been presented in argument of an *Hipparion* ancestry for *Equus* reveals that this point of view is not tenable. Evidence from different parts of the skeletons of late Tertiary horses conclusively demonstrates the descent of *Equus* through *Parahippus*, *Merychippus* and *Pliohippus*. Characters in the teeth are discussed in detail.

The category represented by the North American upper Pliocene horses is not sufficiently different from *Equus* to warrant a recognition of the genus *Plesippus*. The characters listed for this genus are considered here as perhaps slightly more primitive than in Recent and Pleistocene *Equus* but certainly not worthy of the systematic rank ascribed to other Tertiary genera of horses.

THOUGH THE phyletic lines of the horses are better known than in any other family of Tertiary mammals, there are still a few differences in opinion on the lines of descent and genetic relationships of the genera. Some of these pertain to the Pliocene line of descent and the generic status of the genus *Equus*.

In reference to the immediate ancestry of the genus, two main points of view have been presented. Most American and many foreign paleontologists hold that *Equus* is the descendant of a line carrying back through *Pliohippus* to the protohippine species of *Merychippus*. On the other hand some authorities contend that at least some of the species of *Equus* descended from *Hipparion*. It is intended here to review the problem in the light of our more recent information of the groups bearing on these supposed relationships.

IS HIPPARION THE ANCESTOR OF EQUUS?

Kovalevsky (1873) was the first to include *Hipparion* in the direct ancestry of *Equus*. Then in 1888 Pavlov (1888A) considered *Hipparion* as representing a side branch and placed *Protohippus* in the line of descent to the living horse. The evidence for this interpretation, though slightly modified, was increased tremendously by American paleontologists during the early part of the twentieth century—so much so that most vertebrate paleontologists have accepted this point of view. In the meantime, however, Schlosser (1903I; 1907) again supported the position of *Hipparion* in the *Equus* line of descent. This was followed by Abel (1909; 1926; 1928) and Antonius (1919A). Some facts bearing on the characters used by these European authors should be reviewed anew.

Most of the reasons for including *Hipparion* as the ancestor of at least some species of *Equus* were mentioned by Schlosser (1903I; 1907). At that time he relied on Leidy's (1869A) report and miscellaneous small papers by Cope for his information on North American fossil horses. Obviously the critical annectent forms in the New World had not been found. Schlosser, however, recognized a distinction between the American hipparions (*Neohipparion*) and the European forms. *Hipparion*, he thought, was of American origin, and *Anchitherium* he considered as not directly ancestral to *Hipparion*.

Schlosser admits that forms less specialized in the dentition, like *Equus*, are seldom derived from animals like *Hipparion* with more complicated teeth, but he thinks that the *Hipparion-Equus* descent is a probable exception. The following reasons are taken from his (1903I) paper:

(a) *Equus stenonis* Cocchi is morphologically intermediate between *Hipparion* and *Equus*, s.s., as seen in its complicated fossette borders and less compressed protocone.

(b) The prococone is sometimes connected to the protoselene in the premolars of *Hipparion*, and the fossette borders become less complicated toward the base of the tooth. Thus he feels that the *Hipparion* tooth is ontogenetically like that in *Equus*.
(c) Attention is directed to the presence of a protostylid, a parastylid and a hypoconulid as new structures in the lower teeth of *Hipparion*. These structures occur also in the milk teeth of *E. stenonis* Cocchi and the African horses, and may disclose their relationship to *Hipparion*.
(d) A reduction and posterior displacement of the splints in the advanced *Hipparion crassum* Gervais as well as a modification in the metacarpal and carpal facets which he says are much like *Equus*.

Schlosser also favors the opinions of Depéret and Cope that *Equus* is polyphyletic in origin. Thus he thinks that *Hipparion* gave rise to the old world *Equus* and some species of that genus that migrated to North America. Most American species, particularly those from Central and South America, he evidently would consider as descendants of Leidy's *Protohippus perditus*.

Again in 1907 Schlosser discussed the relationship of *Hipparion* and *Equus*.

(a) The lower teeth in *H. crassum* Gervais are like those in *Equus*, but he observes that the upper teeth are like those of *H. gracile* (Kaup).
(b) The facets on the metatarsal of *H. crassum* Gervais are more specialized than in *H. gracile* (Kaup) and closely related forms.
(c) It is difficult to find good evidence for the transition from *Hipparion* to *Equus*.
(d) It is difficult to understand Schlosser's explanation of the contemporaneous occurrence of *Equus* and *Hipparion* in Asia. Evidently he thinks that the oldest species of *Equus* in Asia are migrants from Europe where the *Hipparion* to *Equus* evolution had already taken place, or that the transition stages displayed in European specimens (*Equus stenonis*) tends to recapitulate a process which had taken place in Asia. In the second case, the Asiatic hipparions with connected protocones are the ancestors of *Equus* in that area, and later migrated to Europe. He admits, however, that there is not sufficient evidence to prove these theories.

Abel (1909) accepts the dual origin of the species frequently referred to *Equus*, as proposed by Depéret, Cope and Schlosser, but he questions whether such end groups should be placed in one or two genera. He then asks if we are justified to speak of this as a polyphyletic origin. A misconception held by Abel, and this is prevalent even today, may have affected his conclusion. He states that *Equus* did not reach America until the lower Pleistocene, therefore, since he knew of its occurrence in the upper Pliocene of Eurasia, he would have good reason to assume that it originated somewhere in the Old World. As a matter of fact, the upper Pliocene *Equus stenonis* Cocchi of Europe is very close in its dental characters to the so-called *Plesippus* of the same age in North America. Therefore it is misleading to assume that horses of this group first appeared in the late Tertiary of Europe and did not reach America until the beginning of Pleistocene time. The migration evidently took place at the close of, or shortly after, the middle Pliocene, and it was from North America to Eurasia. After that, intermittent migrations of these horses may have taken place in both directions, but that is difficult to prove or disprove.

In later papers, both Antonius (1919A) and Abel (1926) admit that the majority of *Hipparion* species should be excluded from the ancestry of *Equus*. Nevertheless, they felt that the little *Hipparion matthewi* Abel (probably a synonym of *Hipparion minor* Pavlov) from the island of Samos, which occasionally displays a protocone connected to the protoselene near the base of the tooth, should be the ancestor of some species of *Equus*. Attention is also directed to the fact that the protocone is connected to the protoselene in certain *Hipparion* teeth from China and India. But in 1928 both of these authors seemed certain of the importance of these characters in *H. matthewi* Abel. Antonius was impressed with the fact that annectent forms between these little hipparions and *Equus* had not been found, though he felt that there was still a possibility of their discovery particularly in Africa.

Abel (1928), on the other hand, shifted most of his arguments to the importance of what he assumed to be a new connection of the protocone with the protoselene. He believes that this connection in *Equus* is different in origin from that in *Merychippus* and other horses in that line of descent. The protocone is assumed to have the normal connection with the protoselene in *Merychippus* and *Pliohippus*, but in *Equus* it is

joined to the inner part of the tooth via the "first crochet" (pli caballin) and in this way the genus could have arisen from *Hipparion*. He attempts to prove this assumption with different species of *Merychippus*. In Osborn's (1918A) illustrations of *M. primus* Osborn, Abel observed that no pli caballin was present and that the protocone was still connected with the protoselene. Then, too, he noted that the connection was broken in *Merychippus isonesus* (Cope), but that traces of the connection were still present and a pli caballin had formed. This he evidently thought was an inception of the new connection for *Equus*. Then in *Merychippus paniensis* (Cope), he observed that in an individual there were various stages in the isolation and connection of the protocone. Our collections show a pli caballin developed in *Merychippus primus* Osborn (middle Miocene) as well as every known species of *Merychippus* and *Pliohippus* (fig. 18). The shifting in the position of the protocone can be traced through all intermediate stages from the advanced *Merychippus perditus* (Leidy) to *Equus*. Therefore it would seem that the characters listed by Abel and others for the derivation of at least certain species of *Equus* are untenable.

Schlosser states that *E. stenonis* Cocchi is morphologically intermediate between *Hipparion* and true *Equus* as shown by the complicated fossette borders and less compressed protocone. The similarity to *Pliohippus* in this respect is much greater than in *Hipparion*. Many individual teeth in *Pliohippus* display a marked tendency toward crenulated fossette borders, though this condition is not as advanced as in some of the later species of *Equus*. A similar progression toward complexity in these enamel borders is displayed in late Miocene merychippines and Pliocene hipparions, but in the latter line it is accentuated. The *E. stenonis* Cocchi and the American upper Pliocene equid protocone is foreshadowed in advanced species of the *Pliohippus* subgenus (*Astrohippus*) (see figs. 5, 6).

The connection of the protocone to the protoselene in late stages of wear has been observed in some old-world hipparions, particularly in *H. minor* Pavlov (=*H. matthewi* Abel), and thought to indicate relationship with *Equus* (but see figs. 1, 2). In

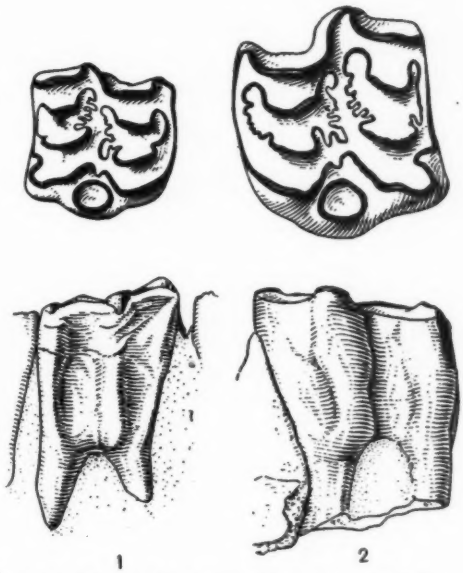


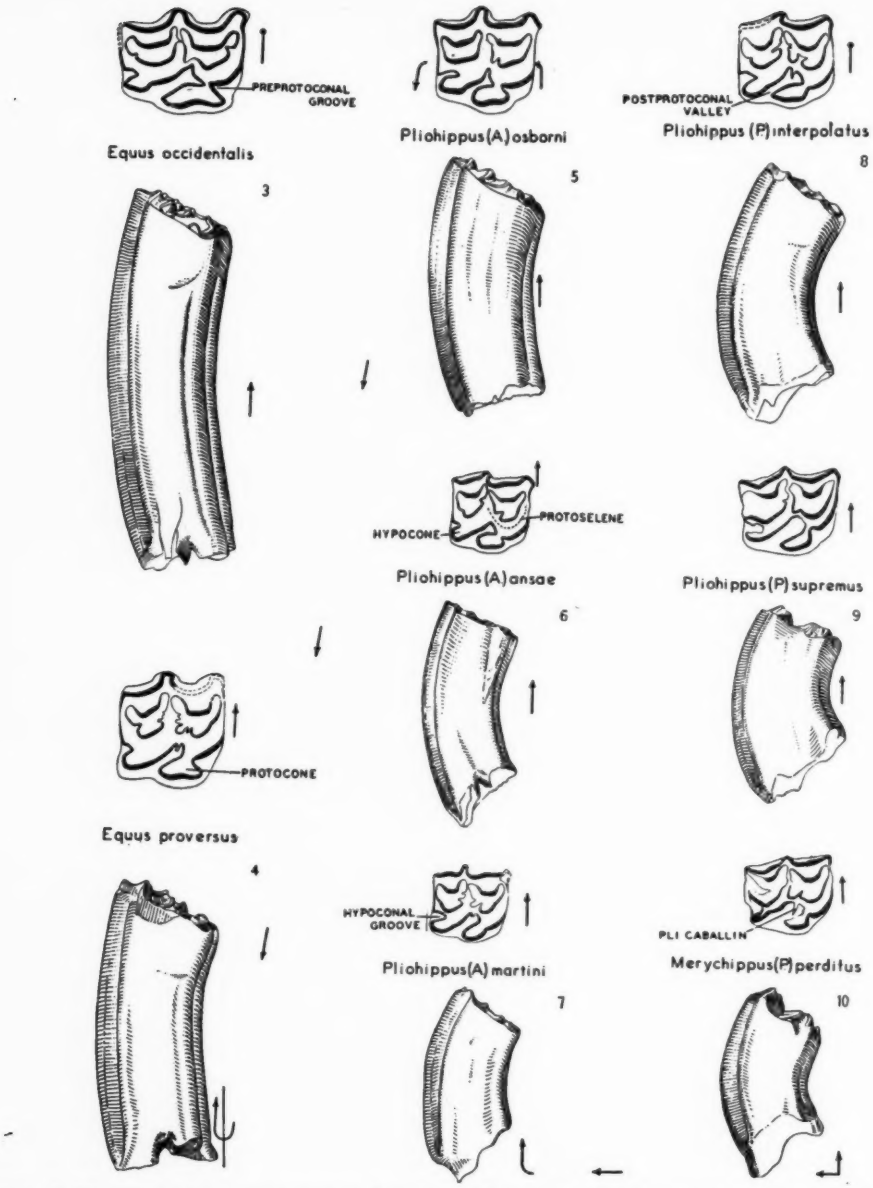
FIG. *1—Hipparion minor* Pavlov?, P^3. Well-worn occlusal and labial views, ×1. Samos Island, Aegean Sea. No. 21743, U. C. Mus. Pal. Though this tooth is well worn, there is no indication of a connection between the protocone and protoselene.

FIG. *2—Hipparion*, P^3. Well-worn occlusal and labial views, ×1. Pikermi, Greece, No. 26745, U. C. Mus. Pal.

America there are two species of *Nannippus*, *N. retusus* (Cope) and *N. gratus* (Leidy), which display this connection much higher in the crown than in any old-world *Hipparion*, yet no one would think of suggesting these as ancestors of *Equus;* the reason being that there are contemporaneous horses much more suitable for this ancestral position. As a matter of fact, this connection of the protocone to the protoselene is evidently the primitive arrangement seen in all early and middle Tertiary horses, and *N. retusus*, *N. gratus* and *H. minor* have shown a tendency to retain this connection.

The significance of the protostylids and parastylids in the lower teeth will be discussed fully on a later page in critical comments on Van Hoepen's (1932) paper. The prominence of a labial extension of the hypoconulid mentioned by Schlosser does not appear to have attracted further attention.

A reduction and posterior displacement



FIGS. *3–10*—All specimens upper premolars, occlusal and posterior views, ×½. Arrows indicate phyletic sequence. *3*, Rancho La Brea, Pleistocene. *4*, Tehama, upper Pliocene. *5*, Mount Eden, middle Pliocene. *6*, Hemphill, middle Pliocene. *7*, Beaver, lower Pliocene. *8*, Hemphill, middle Pliocene. *9*, Burge, lower Pliocene. *10*, Niobrara River, upper Miocene.

of the splints in the advanced *Hipparion crassum* Gervais, as well as a modification in the metatarsal and metacarpal facets are not as much modified in the direction of *Equus* as are these same characters in the American *Pliohippus*. I am not qualified to make a statement on the phyletic position of *H. crassum* Gervais with respect to

the other hipparions, but it is much more distantly removed from *Equus* than is *Pliohippus*. The division of the metaconid and metastylid in the lower teeth of *H. crassum* Gervais, as in all other hipparions, approach the condition seen in *Equus*. This character in the lower teeth is the only one common to *Hipparion* and *Equus* not present in true *Pliohippus*. However, in advanced species of the subgenus *Astrohippus*, there is a widening of the metaconid and metastylid (see fig. 13) which closely approaches that seen in upper Pliocene species of *Equus*. Perhaps this was the character referred to by Schlosser (1907) when he stated that the lower teeth in *H. crassum* Gervais are like those in *Equus*.

As stated previously, one of the more serious difficulties in deriving *Equus* from *Hipparion* is the absence of satisfactory transitional evidence.

Abel's (1928) latest views on the derivation of *Equus* from *Hipparion* as based on a new connection of the protocone to the inner part of the tooth should be considered in the light of observations on additional material. The history of the development of the pli caballin and the isolation of the protocone has been discussed in a previous paper (Stirton, 1941) under the development of the occlusal pattern on the upper teeth. The shifting of the position of attachment of the protocone to the protoselene as seen in *Equus* can be traced back through the ancestors which occur in American late Tertiary faunas. This shift is occasioned by a deepening of the preprotoconal groove (see figs. 3–7). As in the points discussed previously, Abel has failed to produce evidence for the transition from an isolated protocone to this connection via the anterior pli caballin.

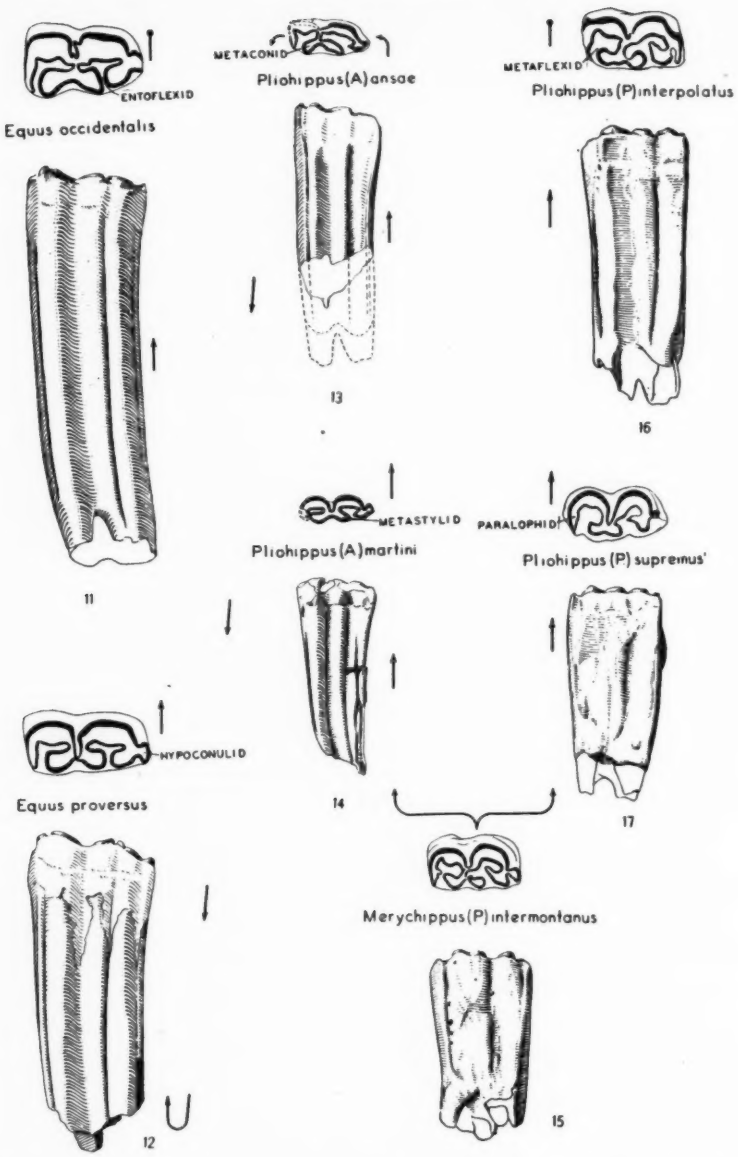
In 1914 Abel proposed the name *Neohippus* for the American species of *Equus* and retained *Equus* proper for the old-world true horses. Various arrangements have been made since, but Antonius (1928) does not agree with Abel. Antonius believes that *Equus* should be recognized in the broadest sense to include the asses, zebras and horses. While he recognizes a possibility of zebras and African asses as being derived from a *Hipparion*, he admits no proof for this contention. Then too, he is not certain of the position of *Equus fraternus* Leidy.

My observations for the most part accord with the views of Antonius, but I consider the possibility of any *Equus* species being derived from *Hipparion* as even more remote. As he suggests, a sound interpretation of the phyletic lines of the *Equus* species must await more information.

The descent of *Equus* was also considered by Van Hoepen (1932) when he based his interpretation on the development and degeneration of the parastylid. He contends that the parastylid loop derived from *Merychippus* developed into a more restricted loop and finally became an isolated column in the upper part of the tooth of the later horses. The loss of the parastylid, he thinks, is occasioned by the development of an evagination or loop of enamel in the metaflexid which occurs on the inner wall opposite the lingual opening. This, Van Hoepen believes, has taken over the reenforcement function of this part of the tooth in later hipparions, and therefore the parastylid disappears. He cites *Hipparion mohavense callodonte* Merriam as an example in which the evagination of the metaflexid is strongly developed and the parastylid is lost. However, he thinks that a thickening of the outer enamel may also have relieved the parastylid of part of its strengthening function.

Van Hoepen finds through this interpretation another possibility of deriving *Equus* from *Hipparion*. Though he believes that the horses, the zebras and asses, and two extinct African genera represent three distinct lines of descent, he concludes that the zebra is a descendant of a *Hipparion* with parastylids on P_{3-4} since these structures occur in the zebra. He also believes that asses are derived from the zebras because the parastylids are well developed on lower milk teeth of zebras and present though weaker in deciduous teeth of asses. He would derive what he calls the horse from a *Hipparion* without parastylid folds, and he intimates that *H. mohavense callodonte* Merriam would be a likely ancestor but admits that *Pliohippus* could be the ancestor.

The most serious criticism of Van Hoepen's views on the origin of *Equus* is true of all similar postulations in which *Hipparion* is considered the ancestor. This is a



FIGS. *11–17*—All specimens lower premolars except *14*, which is a molar, occlusal and lingual views, ×½. Arrows indicate phyletic sequence. *11*, Rancho La Brea, Pleistocene. *12*, Tehama, upper Pliocene. *13*, Hemphill, middle Pliocene. *14*, Beaver, lower Pliocene. *15*, Barstow, upper Miocene. *16*, Hemphill, middle Pliocene. *17*, Burge, lower Pliocene.

failure to consider carefully the overwhelming evidence from America, which demonstrates almost intergradational evolution from the upper Miocene *Merychippus* (*Protohippus*) *perditus* (Leidy) through a succession of Pliocene species. As pointed out elsewhere in this paper, this is not based on one or two characters in the upper or lower teeth, but on numerous characters in the dentition, limbs and feet. He agreed

with Sefve (1927A), however, that the reasons given by Schlosser (1903I), Abel (1909; 1926), and Antonius (1919) do not supply positive proof for the derivation of *Equus* from *Hipparion*. Apparently he also agreed with Stehlin (1928) in rejecting Abel's (1928) latest arguments.

Some of the points discussed by Van Hoepen merit further consideration. The statement that the isolated column on the anteroexternal corner of lower teeth (=parastylid) does not appear in the American hipparions is not supported by the evidence in our collections. Though the isolation is not as persistent nor as complete in the new-world forms as in some Eurasiatic hipparions (*Hipparion platyodus* Sefve), it does appear in early stages of wear in some teeth (fig. 20). This is true not only in *Neohipparion* but in *Nannippus* and *Pliohippus* though extremely rare in the latter.

The stages in the disappearance of the parastylid recognized by Van Hoepen seem to be well supported, but it is felt that the evagination in the metaflexid in no way occasioned the loss of the parastylid. On the other hand, the thickening of the external enamel as he suggests could have some effect. The evagination within the metaflexid may well have been preserved within the metaflexid because it occupied a protected position on the tooth. It should be noted, however, that the reason for the presence of a parastylid loop in the illustrations of *Neohipparion whitneyi* Gidley and not in *H. mohavense callodonte* Merriam is that the latter is in an early stage of wear. The loop occurs in the lower half of *H. m. callodonte* teeth (fig. 21). Van Hoepen observed that there is no parastylid either in the permanent or milk teeth of *Equus caballus* Linnaeus, but that they are present not only in milk teeth but in P_{3-4} of the zebra. They also occur, but less pronounced, in the milk teeth of the ass. He concludes, then, that the zebras stand nearest to *Hipparion*, while the asses are farther away but still are derived from the zebras. The features mentioned here may be used with even greater propriety in considering *Pliohippus* as the ancestor of these forms. Not only do *Pliohippus* species possess the characters mentioned by Van Hoepen but numerous other similarities to *Equus* occur in the dentition and skeleton.

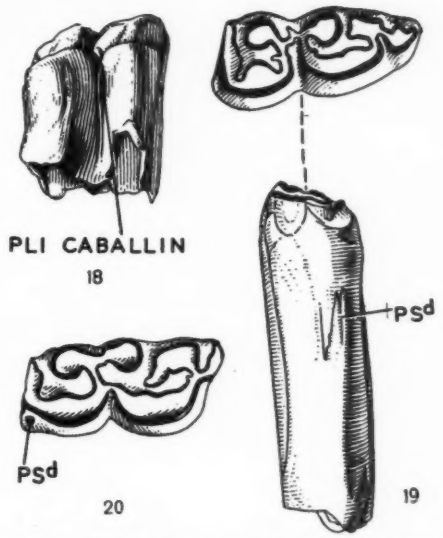


FIG. *18*—*Merychippus* cf. *primus* Osborn, upper premolar with protocone removed to show pli caballin, ×1. Sheep Creek, middle Miocene. No. 29935, U. C. Mus. Pal.

FIG. *19*—*Hipparion mohavense callidonte* Merriam, lower molar, occlusal and anterior view, ×1. Ricardo, lower Pliocene. No. 21311, U. C. Mus. Pal., part of type specimen. PS^d, parastylid.

FIG. *20*—*Neohipparion coloradense* Osborn, lower premolar, occlusal view, ×1. Burge, lower Pliocene. No. 35453, U. C. Mus. Pal. PS^d, parastylid.

In a detailed study of the feet of the Equidae, "Phylogeny and functions of the digital ligaments of the horse" (California Univ. Mem. in press), C. L. Camp and Natasha Smith have observed significant differences in the proximal phalanges of the hipparions and *Equus*. Their studies on these elements in the subgenus *Astrophippus* reveal pre-*Equus* affinities distinct from *Pliohippus*, s.s., distantly different from the hipparions.

It is difficult to understand why so much effort has been made to derive *Equus* from the Eurasiatic *Hipparion*. When Schlosser first returned to this point of view in 1903, the evidence from America was still very incomplete and there was some merit in the points he discussed. Since then, however, much evidence has been produced from different parts of the skeleton to demonstrate conclusively the descent of *Equus* through

Parahippus-Merychippus-Pliohippus. Only certain minor discrepancies appear, and they are being adjusted from time to time. Therefore most American paleontologists are at a loss to understand the persistency in the *Hipparion-Equus* point of view, since all of the arguments presented are beclouded in uncertainty.

IS PLESIPPUS OF GENERIC RANK?

Another controversial subject is the generic status of *Plesippus* Matthew (1924d) The name is applied to upper Pliocene horses that are supposed to be intermediate between advanced species of *Pliohippus* and *Equus. Equus simplicidens* Cope from the Blanco fauna of Texas is the genotypic species. The species assigned to this genus are thought to define a recognizable phyletic unit restricted to the American upper Pliocene. An alternative point of view is that the characters listed (Matthew 1924d, 1926c; Gidley 1930; Schultz 1936; Gazin 1926) represent only a slightly more primitive condition in the species of the genus *Equus.*

A list of the characters that have been assigned to *Plesippus* are included here and followed by critical comments.

MATTHEW (1924D)

1. Size and limb proportions of average Pleistocene horse.
2. Teeth most like *Pliohippus,* but larger and more robust than true *Pliohippus.*
3. Teeth most like *Pliohippus,* but longer-crowned and less curved, with heavier mesostyle and larger and more nearly isolated protocone.
4. Cement lakes of upper molars narrower, and enamel borders have simple inflections.
5. Skull has elongate proportions of *Equus.*
6. Vestigial trapezium and fifth digit present.
7. Splints nearly or quite as reduced as in *Equus.*

MATTHEW (1926E)

1. Size and proportions of Arab horse.
2. Hoofs much smaller.
3. Back shorter;
4. and the barrel less rounded and convex.
5. Lateral digits or splints end in a thin, flattened and expanded sliver.
6. The fibula is reduced to a splint which in *Plesippus* is distinctly shorter than in any species of *Equus.*
7. Skull with shallow facial pockets or fossae more reduced than in *Pliohippus.*

GIDLEY (1930)

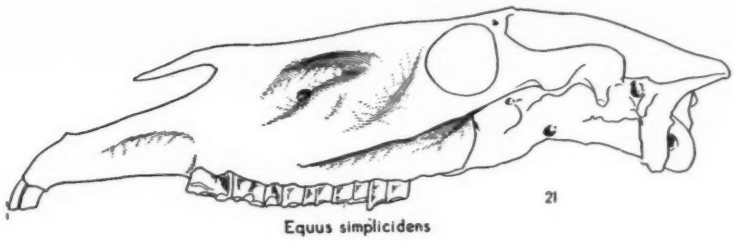
1. Cranium short and markedly deflected from the distinctly elongate facial proportion.
2. Preorbital fossa anterior to the lacrymal bone is conspicuously developed along the line of the suture between the nasal and maxilla.
3. Rostrum deep anteriorly and narrow across the nasals.
4. First premolar above well developed and always present.
5. First premolar below simple and commonly present in young individuals.
6. Cheek teeth approach in appearance those in *Equus,* somewhat more so in the early stages of wear.
7. Feet comparatively small, splint bones reduced but with their average length relatively greater than in *Equus.*
8. Trapezium usually present.

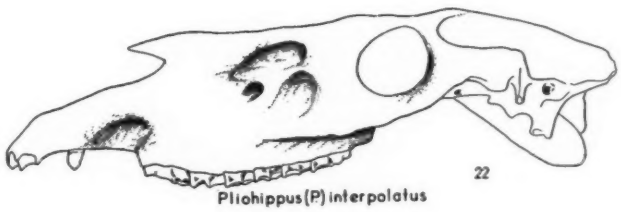
Some of the characters listed here are too variable for further consideration, but others merit discussion.

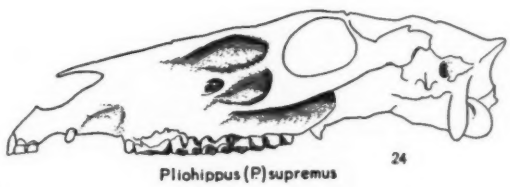
A comparative study of all *Pliohippus* and *Equus* teeth available reveals that the upper Pliocene forms are much closer to *Equus.* The genotypic species of *Pliohippus* is the lower Pliocene *P. pernix* Marsh and is not an advanced type as the species in the genus are now recognized. Indeed, when the dental characters as a whole, even in such advanced forms as the middle Pliocene *Pliohippus interpolatus* (Cope), are compared, it is found that the upper Pliocene teeth are much closer to the later horses.

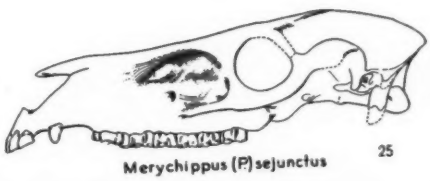
Pliohippus cheek teeth differ from those in *Equus* in their smaller size (for a tooth practically identical in size with that in the genotypic species of *Pliohippus,* see figure of *P. supremus* (Leidy)), in their shorter crown height, in the curved upper teeth, in the protocones without a lingual groove, and in the metaconids and metastylids, which tend to converge toward the base of the teeth.

There are some exceptions to the smaller size, as in *Equus tau* Cope and in some of the zebras and Recent horses, but the height and straightness in the teeth readily distinguish them. There is a gradual increase in height of crown in these Pliocene horses, but on the whole those from the middle Pliocene are more like typical *Pliohippus.* The upper Pliocene teeth are for the most part shorter than in the later *Equus,* but the zebra and several Recent horses possess teeth equally short. In the pre-*Equus* horses (subgen. *Astrohippus,* figs. 5–7), a gradual straightening of the tooth is apparent. This is of course approaching the condition seen in *Equus,* but again the degree of curvature









FIGS. *21–25*—Lateral views of skulls to show preorbital fossae, ×⅛. *21*, Blanco, upper Pliocene. *22*, Hemphill, middle Pliocene. *23*, Clarendon, lower Pliocene. *24*, Burge, lower Pliocene. *25*, Pawnee Creek, upper Miocene.

displayed, together with other characters in the teeth and feet, show rather profound relationship to the basal stem of *Pliohippus*.

The tendency to a foreshortening of the protocone and the shallow lingual groove in upper Pliocene horses have been thought of as *Pliohippus* characters, but these same features are present in the Arabian horse, the plains mustang and in the zebras. Finally the metaconid and metastylid are V-

shaped and not widely U-shaped as attributed to *Equus*. Again a glance at the Recent forms mentioned above will demonstrate that these characters are not restricted to the upper Pliocene *Equus*, nor do they indicate a closer relationship with *Pliohippus*.

The presence of a large P^1 is so persistent in the Hagerman upper Pliocene horses that it has also been used in defining the genus *Plesippus*. This feature may be restricted to some upper Pliocene species, but we do not know that all equids in this line and of this age are so characterized. There is no reason that they should, since it is not true in *Pliohippus*. In that genus it varies from being well developed in *P. fossulatus* (Cope) to being vestigial or absent as in *P. interpolatus* (Cope). Even in some Hagerman specimens the tooth was vestigial. A generic rating of this character might be questioned.

Shallow facial fossae occur in both *Equus simplicidens* Cope from the Blanco and *Equus shoshonensis* (Gidley) from Hagerman. Matthew states that those in *E. simplicidens* are much shallower than in *Pliohippus*, but a skull of *P. interpolatus* (fig. 22) displays fossa little if any deeper than in the Blanco skull. Even in specimens referred to *P. fossulatus* from the Clarendon fauna of Texas (fig. 23), there is a much greater difference in the preorbital fossae than between *Plesippus* and *Equus*. If these differences in the preorbital fossae are to be used as criteria of generic distinction, the known species of *Pliohippus* may well be divided into five or more genera. They could be based on such species as *P. supremus*, *P. fossulatus*, *P. ansae*, *P. interpolatus* and *P. coalingensis*. In view of the extreme variation seen in these fossae in *Pliohippus*, then it seems a bit impracticable to consider them of generic value in the upper Pliocene species.

Cryptocephally, the degree of flexure of the basicranial and facial axes is greater in the upper Pliocene skulls than in later horses as shown by Gazin (1936). This, however, is a matter of degree and is much closer to *Equus* as a whole than to the known skulls of *Pliohippus*.

Such degenerate structures as the fibula, trapezium and splints are liable to be quite variable and not worthy of much consideration in close phyletic interpretations. They may be of some significance, though, in tracing phyletic lines of *Equus* when the species are better known.

The interesting fact regarding the characters used in diagnosing *Plesippus* is that they are preserved in one or another of the Recent or Pleistocene species, and some in different combinations with the possible exception of the preorbital fossae. This certainly militates against an upper Pliocene unity for the genus. It is true that there are some distinctions in the Hagerman assemblage as pointed out by Gazin (1936); but these are no more than specific characters as used in the diagnosis of the species of *Merychippus*, *Pliohippus*, *Nannippus* or other equid genera that might be mentioned. An alternative would be to refer all members of the subgenus *Astrohippus* to *Plesippus*, thus extending the genus back into the lower Pliocene. This was not done because the characters in *Pliohippus* (*A.*) *martini* (Hesse) and *Pliohippus* (*A.*) *ansae* (Matthew and Stirton), though showing a definite trend toward *Equus*, are much closer to *Pliohippus*, s.s. Even *Pliohippus* (*A.*) *osborni* Frick, though displaying rather profound *Equus* affinities, is still clearly referable to the older group. On the other hand, the upper Pliocene species are very close to the Pleistocene horses; so much so that it usually requires the associated fauna to be certain of their age. *Plesippus*, then, may be referred to more properly as *Equus*.

SUMMARY

It seems wholly unnecessary to seek an ancestry for *Equus* in the old world *Hipparion;* and *Plesippus* is considered as part of the genus *Equus*. The evidence reviewed here indicates that the species of *Equus* in its broadest sense (horses, zebras and asses) are derived from the protohippine horses and not from the hipparions. If *Equus* is polyphyletic, this term can be used only in the sense that the various species are derived from different species in the two subgenera (*Pliohippus* and *Astrohippus*) of Pliohippus. It is true that there are certain obvious distinctions between the ass, the zebra, and the horse, but it seems impracticable to consider them under separate generic names; especially since it throws

their systematic rank out of harmony with the other genera in an established phylogenetic sequence. Certainly there is no sound basis for deriving *Equus* species from widely divergent ancestry.

Assistance in the preparation of this manuscript was furnished by the personnel of the Work Projects Administration, Official Project no. 65-1-08-62, Unit A-1.

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JOURNAL OF PALEONTOLOGY, VOL. 16, NO. 5, PP. 638–639, PL. 91, SEPTEMBER, 1942

EARLY CAMBRIAN "FORAMINIFERA"

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Princeton, N. J. and State College, Miss.

ABSTRACT—Globular objects, believed to be fossil foraminifera, are described from the Lower Cambrian Ella Island formation of East Greenland. Assigned by Poulsen in 1932 to an unnamed species of *Lagena*, they are here described as the new species *Psammosphaera? greenlandensis*. Similar objects from the Lower Cambrian Forteau formation of Labrador, probably also fossil foraminifera, are figured, but not described or named.

PALEONTOLOGISTS have been searching for Cambrian and Pre-Cambrian foraminifera for many years, but evidence of the existence of these small fossils in those early times has been conspicuous by its almost complete absence. A great part of what has appeared to be evidence of their presence has been discarded for various reasons, and to this date the oldest undoubted foraminifera known are those from the upper Cambrian beds of the Malvern Hills of England (Howell and Sandidge, 1933).

Through the courtesy of Dr. Chas. E. Resser of the United States National Museum and Dr. Christian Poulsen of the University of Copenhagen, the writers have been permitted to study some peculiar small globular objects, preserved in limestone, from the Lower Cambrian of Forteau Point, Labrador and of Ella Island, East Greenland. The specimens from East Greenland, which were described by Poulsen (1932) as unnamed species of *Lagena*, are well preserved and are here described and named. Those from Labrador are so badly weathered that it has been impossible to determine with certainty what is their relationship with those from Greenland. These Labrador specimens are therefore figured here, but are not named or described.

After carefully studying these little spherical objects from Greenland the authors have decided that they are worthy of description, although conclusive proof that they are foraminifera cannot now be presented. It is hoped that the description and figures of them which are here given may be of assistance to students who may have occasion to deal with similar objects in the future.

Parts of the two hand specimens of gray limestone containing the East Greenland "fossils" seem to be made up almost completely of these small, round, oolitelike objects, which have been brought out in bold relief on the surface by weathering. When we first examined these small objects we thought that they were perhaps concretions; but further examination has led us to believe that they are more probably fossil foraminifera.

These objects are hollow balls of white calcite, some with their centers filled with clear calcite. This clear calcite was at first thought to be a nucleus but later was proved to be secondary filling in the limestone, since other associated hollow fossils, identified as shells of *Salterella rugosa* Billings, contained the same material.

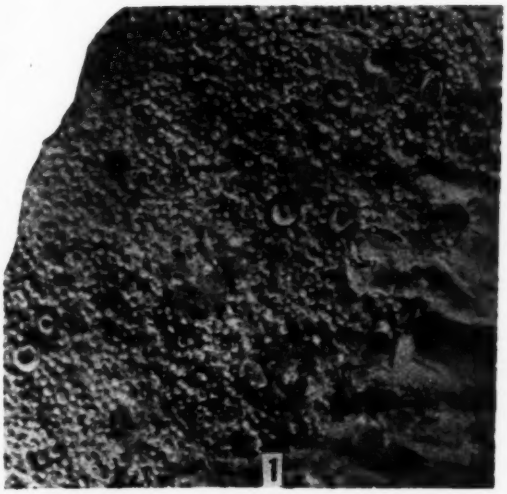
A few of these balls were isolated and submerged in a weak solution of HCl. There was almost instantaneous reduction of the calcite, but there was a fair amount of arenaceous material left as a residue.

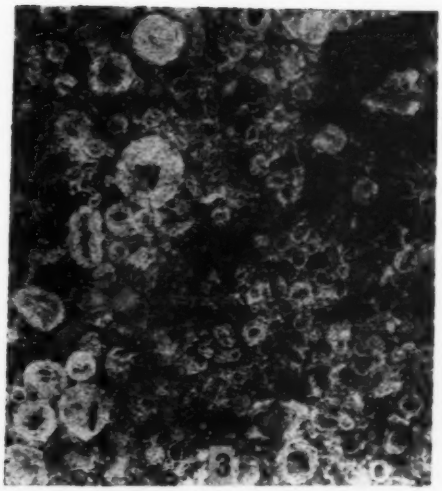
The fossils of *Salterella rugosa* in the

EXPLANATION OF PLATE 91

FIGS. *1, 2*—*Psammosphaera? greenlandensis* Howell and Dunn, n. sp. Syntypes, on weather-etched surface of Ella Island limestone. *1*, ×2.5; *2*, ×12. The larger fossils are cross sections of *Salterella rugosa* Billings. (p. 639)

3—Foraminifera? from Forteau limestone at Forteau Point, Labrador, U. S. Nat. Mus. 108081, ×5. (p. 638)





Howell and Dunn, Early Cambrian "Foraminifera"

UNIV. OF MICH.

same pieces of rock with the "foraminifera" were found to be composed of the same type of calcite as the little balls. This would seem to prove that all the fossils in the limestone have passed through a period of replacement, crystalline calcite having been substituted for the original material. The substance of which the original test of the "foraminifera" was composed was evidently "chitin" (tectine), containing a small amount of arenaceous material. Some of the Malvern Hills foraminifera described by Chapman may have been related to those here described, but the presence of arenaceous material in the tests of the English specimens has not been suggested.

Yabe and Hanzawa (1935) have described as "foraminifera(?)" small spherical bodies from the Ordovician of Manchuria which resemble our Greenland balls. Those authors noted, however, that when the Manchurian specimens were treated with diluted acid, thin round tests were left in the residue. In our study no tests were found after the acid treatment, but arenaceous material was present.

As we have had only a small amount of this material which we could study, we have not been able to make a more exhaustive study of these interesting objects; but it is believed that sufficient information has been obtained to prove that they are organic in origin and that they are probably fossil foraminifera.

We wish to express our thanks to Dr. Joseph A. Cushman for advice given in the course of the study of our Greenland material.

SYSTEMATIC DESCRIPTION

Order FORAMINIFERA

Family SACCAMMINIDAE

Genus PSAMMOSPHAERA? Schultze, 1875

PSAMMOSPHAERA? GREENLANDENSIS Howell and Dunn, n. sp.

Plate 91, figures 1, 2

Test free, large, spherical; wall of white crystalline calcite, with a small amount of fine arenaceous material; center cavity often filled with clear calcite; aperture indefinite. Diameter 0.50 mm.

Occurrence.—Ella Island formation, lower Cambrian, southern coast of Ella Island, East Greenland.

Remarks.—The crystalline calcite has replaced the original cementing material, which was evidently "chitin" (tectine). We were not able to distinguish the different kinds of apertures which Poulsen recognized in some of his specimens from Ella Island.

Location of types.—The syntypes (the specimens figured here) will be delivered to the University of Copenhagen when conditions permit of their safe transportation. Paratypes are no. 52753 in the paleontological collection of Princeton University.

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JOURNAL OF PALEONTOLOGY, VOL. 16, NO. 5, PP. 640–642, PL. 92, SEPTEMBER, 1942

LOCKHARTIA IN CUBA

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ABSTRACT—A new species of the foraminiferal genus *Lockhartia*, which genus heretofore has been reported only from the Paleocene and lower Eocene of India and Somaliland, occurs in Pinar del Rio, Cuba. It is associated with *Miscellanea catenula* (Cushman and Jarvis) in beds supposed to be of Upper Cretaceous age. Both species are described and figured.

THE GENUS *Lockhartia* was erected by Davies (1932, pp. 406–408) for certain foraminifera that had been assigned previously to the genus *Dictyoconoides*, from which they differ in not developing any intercalary whorls in the spire. Davies referred to it four species and one variety, which occur in the Paleocene and lower Eocene of India and Somaliland. Collections from Pinar del Río Province of Cuba made by Dr. Pedro Bermudez contain a new species that evidently should be referred to *Lockhartia*. The geographic range of the genus is thus extended to the West Indies.

The specimens were collected in an area mapped by Vermunt (1937) as Habana formation (Upper Cretaceous) combined with lower Tertiary. They were associated with the form described by Thiadens (1937, pp. 94, 95) as *Camerina vermunti* (here referred to *Miscellanea catenula* [Cushman and Jarvis]) from the Upper Cretaceous of Santa Clara Province, Cuba, where it occurs in association with *Orbitoides palmeri* Gravell, several species of *Lepidorbitoides*, and other genera, all of which are characteristic Upper Cretaceous forms. A fragment doubtfully identified as *Meandropsina? rutteni* Palmer was also found. The supposition seems warranted, therefore, that the beds containing the *Lockhartia* are Upper Cretaceous rather than early Tertiary. If this is so, the geologic range of *Lockhartia* is extended to the Upper Cretaceous. This is analogous to the recent determination by Davies (1939, p. 776) that *Dictyoconus*, which had been considered to be a typical Eocene genus, originated in the Cretaceous.

Family CAMERINIDAE
Genus MISCELLANEA Pfender, 1934
MISCELLANEA CATENULA (Cushman and Jarvis)
Plate 92, figures 6–10

Operculina catenula CUSHMAN and JARVIS, *1932*, U. S. Nat. Mus. Proc., vol. 86, no. 2914, p. 42, pl. 12, figs. 13a, b.
Camerina? dickersoni D. K. PALMER, *1934*, Soc. cubana historia nat. Mem., vol. 8, p. 243, pl. 14, figs. 1, 2, 4, 6, 8.
Camerina? cubensis D. K. PALMER, *1934, idem*, p. 245, pl. 14, figs, 3, 5, 7.
Camerina vermunti THIADENS, *1937*, Jour. Paleontology, vol. 11, p. 94, pl. 16, figs. 1, 11, 12; text figs. 2C, 3A, E.
Camerina dickersoni, VOORWŸK, *1937*, K. Akad. Wetensch. Amsterdam Verh., vol. 40, p. 191, 192, pl. 2, figs. 11–16; pl. 3, figs. 3, 6.
Operculinoides catenula, BARKER, *1939*, U. S. Nat. Mus. Proc., vol. 86, no. 3052, p. 320, pl. 14, figs. 6, 8; pl. 18, fig. 5; pl. 21, figs. 7, 8.
Camerina? dickersoni, Barker, *1939, idem*, p. 326, pl. 20, fig. 3; pl. 21, fig. 12.

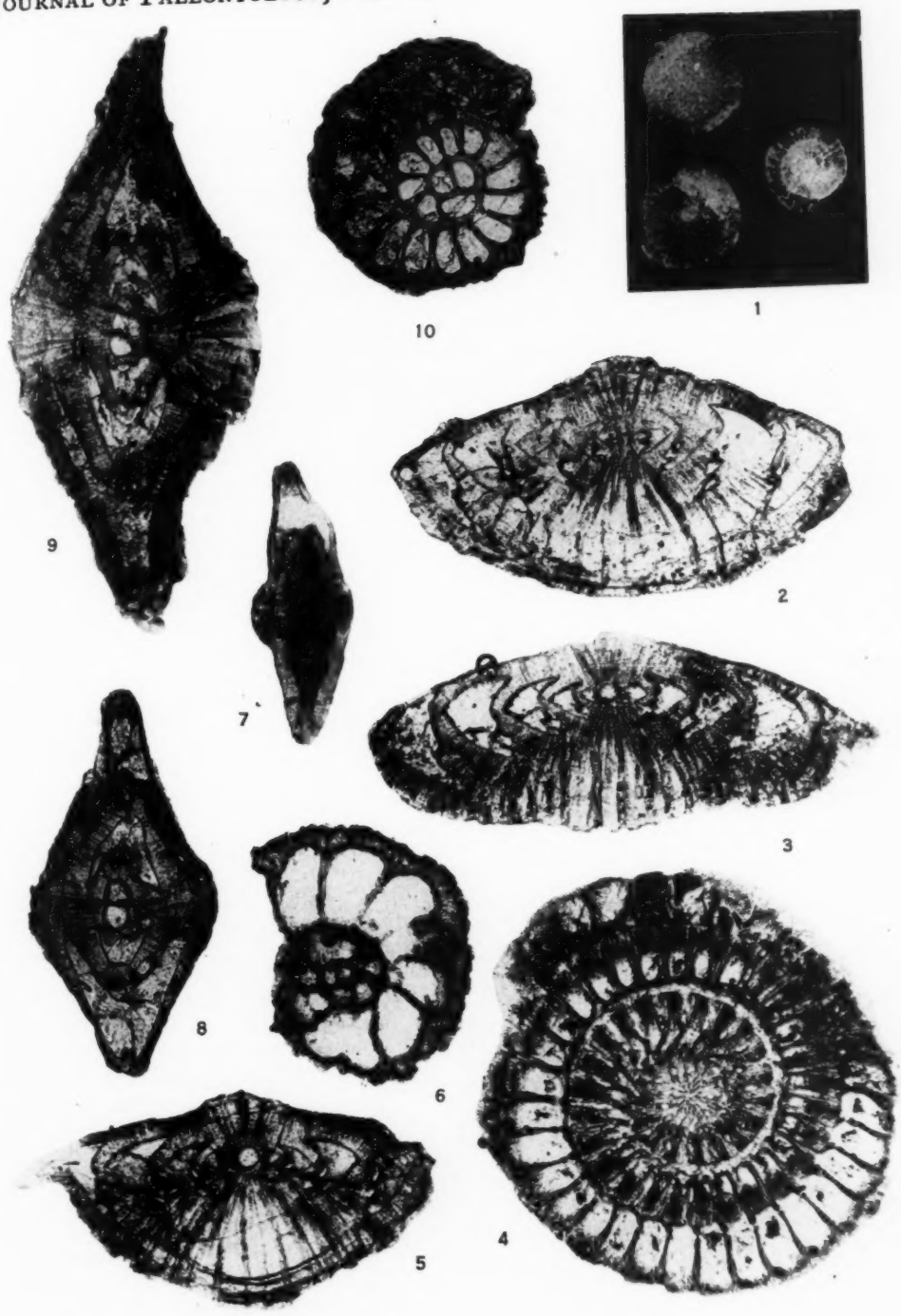
Test small, completely involute, slightly asymmetrically lenticular with reference to the median plane, thickest in the center sloping gradually outward, but flattening rapidly near the periphery. The periphery of the test is composed of two rows of closely packed plates, which give it a fringed appearance. Between the rows of plates there is a shallow V-shaped depression, which encircles the test. Surface ornamentation

EXPLANATION OF PLATE 92

All figures ×41 except figure *1*, ×10.

FIGS. *1–5*—*Lockhartia bermudezi* Cole, n. sp. *1*, External views of syntypes. *2*, *3*, *5*, Vertical sections. *4*, Horizontal section. *3*, *4*, Paratypes. *1*, *3*, *4*, Bermudez sta. 537. *2*, *5*, Bermudez sta. 538. (p. 641)

6–10—*Miscellanea catenula* (Cushman and Jarvis). *6*, *10*, Median sections. *7–9*, Transverse sections. *6*, *7*, Topotypes of *Camerina? dickersoni* D. K. Palmer from 1 kilometer west of Baños de Ciego, Santa Clara province, Cuba. *8–10*, Bermudez sta. 537 (p. 640)



Cole, Upper Cretaceous? Foraminifera

UNIV. OF MICH.

consists of a large, prominent, slightly elevated, central boss, from which radiate straight, slightly raised sutures of clear shell material. The area between the sutures is without ornamentation. A specimen with a diameter of 1.3 mm. is 0.64 mm. thick; a specimen with a diameter of 2.12 mm. is 0.86 mm. thick.

A horizontal section of a specimen with a length of 0.86 mm. shows two whorls with 17 chambers in the final volution. The initial chamber is subspherical in shape with internal diameters of 80 by 60μ. The second chamber has internal diameters of 100 by 100μ. The partition separating the two chambers is straight. The chamber walls are nearly straight and radial, although a few slightly recurve as they approach the periphery. Slit apertures lie near the inner margins of the septa. Slight anteriorly directed lips are developed on either side of the slitlike aperture (pl. 92).

A specimen 1.66 mm. long has two and seven-eighths whorls with about 23 chambers in the final volution. Another specimen 1.95 mm. long has three whorls with about 24 chambers in the final volution. In this section the initial chamber appears to be circular, with an internal diameter of 70μ. Certain septa seem to broaden as the periphery is approached, so that a light inwardly projecting triangular area is formed between the darker walls of the septum. This is not true of all the septa.

Vertical sections indicate that the central boss seen in external views is composed of a series of small closely packed pillars, which extend outward from the embryonic apparatus and increase in size toward the periphery. The surface diameter of this boss ranges from 0.24 to 0.40 mm. depending on the size of the specimen. The central group of pillars is normally slightly better developed on one side of the test than the other.

The spiral suture has a small, V-shaped groove, which is a very distinctive feature in vertical sections. The walls of the spiral lamina are coarsely perforated by vertical canals.

Affinities: Three species that closely resemble each other have been described from the Upper Cretaceous of Cuba: *Camerina? dickersoni* and *C. cubensis* by Mrs. Palmer (1934, pp. 243–246) and *C. vermunti* by Thiadens (1937, pp. 94, 95). Voorwijk (1937, pp. 191, 192) considers that *cubensis* and *vermunti* do not show sufficient differences from *dickersoni* to justify the retention of these specific names. Barker (1939 p. 327) states that

> The principal difference between *C. dickersoni* and *C. vermunti* (from a study of Mexican specimens of the fomer) seems to be in the form of the septa, which are much thicker and more recurved in the former species.

Mrs. Palmer kindly sent the writer four topotype specimens of *C. dickersoni*. A horizontal section from a megalospheric individual and a vertical section from a microspheric individual are introduced on plate 92, figs. 6, 7, for comparison with the specimens associated with *Lockhartia*.

Cushman and Jarvis (1932, p. 42) described *Operculina catenula* from the Upper Cretaceous at Lizard Springs near Guayagmayare, Trinidad, B.W.I. Barker (1939, pp. 320, 321) referred certain Mexican specimens to this species, although he placed it in the genus *Operculinoides*. These specimens appear to be similar to the Cuban specimens.

Thalman (1938, p. 330) created a new subgenus *Sulcoperculina* with *Camerina? dickersoni* as the subgenotype. This subgenus was placed under the genus *Operculina*.

Without examination of the type specimens, it is impossible to decide questions that have been raised. However, the writer is of the opinion that Voorwijk is correct in combining *dickersoni-cubensis-vermunti* under one specific name. It seems highly probable that the *dickersoni* group might be combined with *catenula*, as the figures given by Barker suggest that the internal structure of *catenula* is the same as that seen in *dickersoni*.

Occurrence.—Kilometer 10 (Bermudez station 537) and 200 meters N. 23°W. of kilometer 9 (station 538) on the road from Pinar del Río to Luis Lazo.

Family ROTALIIDAE

Genus LOCKHARTIA Davies, 1932

LOCKHARTIA BERMUDEZI Cole, n. sp.

Plate 92, figures 1–5

Test small, unequally biconvex, ventrally more convex than dorsally, diameter from

0.89 to 1.8 mm., thickness from 0.46 to 0.92 mm. Average-sized adult individuals have a diameter of about 1.5 mm. and a thickness of about 0.7 mm. Perfectly preserved individuals have the dorsal side smooth and unornamented except for a small apical boss of clear shell material; the ventral side is covered with coarse pits except for a narrow band adjacent to the periphery, which is smoother and shows the sutures of the chambers which comprise the final whorl. Slightly weathered specimens exhibit on the dorsal side straight sutures which radiate from the apical boss to the periphery. In some specimens these radial sutures break up into a series of small knobs or beads as they approach the central boss.

A horizontal section of a specimen with a diameter of 1.4 mm. shows four and three-quarters whorls with 26 chambers in the final volution. A specimen with a diameter of 1.6 mm. had 32 chambers in the final whorl. The chamber walls are usually straight and radial. Occasionally, some are very slightly recurved. Slitlike apertures occur near the proximal end of the radial chamber walls. The chambers increase but slightly in size as added, and normally the final chambers are reduced in size.

Vertical sections show pillars that extend from the embryonic chambers in a dorsal and ventral direction. The ventrally directed pillars are large and strong, occupying a considerable portion of the interior of the test, but the dorsally directed pillars are small and more or less fused together, so that they form the central boss. The ventrally directed pillars are separated from each other. The initial chamber is spherical, with an internal diameter of about 75μ. The inner ends of chamber walls are flattened and slightly expanded where they abut against the umbilical pillars.

Affinities: L. bermudezi belongs to the group in which Davies (1937, p. 407) places *L. newboldi* and *L. conditi*. All of these have typically smooth dorsal surfaces, and the inner ends of the chamber walls are flattened and expanded where they abut against the umbilical pillars. *L. conditi* has fewer chambers in the final whorl than *L. bermudezi*. The chamber walls of *L. conditi* are more recurved, and there are fewer and thicker umbilical pillars. *L. newboldi* is approximately the same size as *L. bermudezi*. There is, however, a marked difference in the vertical sections.

It is a distinct pleasure to be able to name this species after Dr. Pedro J. Bermudez, who has given us so much information concerning the Cuban smaller foraminifera.

Occurrence.—Kilometer 10 (Bermudez station 537) and 200 meters N. 23° W. of kilometer 9 (station 538) on the road from Pinar del Río to Luis Lazo.

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RECURRENCE OF MORPHOLOGIC TYPES AND EVOLUTIONARY CYCLES IN MESOZOIC AMMONITES

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ABSTRACT—Examples of striking resemblances, both in shape and in ornamentation, between forms, or even groups, of ammonites of quite different geological age have long been known. They are not, as Steinmann (1908, 1909) erroneously asserted, due to persistence of races, but are merely due to recurrence of morphologic types. In some cases even the same differentiation of certain types as to their whorl sections, degree of involution, character of costation, etc., recurs within groups separated by wide time intervals. However, not only types and groups of types reiterate themselves in the history of ammonites, but also certain evolutionary cycles, each proceeding along definite anagenetic trends, e.g. from evolute, sturdy forms with coarse and stiff costation to more involute and discoidal ones with a finer and more sigmoidal ribbing; also there is the same increase of the elaborateness of the suture lines in each of these cycles. Similar thoughts have been expressed, in a more general sense, or with regard to other groups, in recent papers of Schindewolf (1940: "iterative repetition of the same evolutionary course") and of Zoch (1940: "repetition of trends of forming forces").

Naturam expellas furca, tamen usque recurret.
Hor., Ep., I, 10, 24

THE IDEAS expressed in the present paper originated, quite automatically, from the writer's work on various Mesozoic ammonite faunas—A Middle Liassic one, studied about thirty years ago, showed a gradual transition from late arietitids to early harpoceratids. The occurrence of *Arietites*-like forms (*Tropigastrites*) in a Middle Triassic collection from Nevada, worked up at the Museum of Comparative Zoology of Harvard University, struck me two years ago. Soon afterwards I encountered various forms strongly reminiscent of Liassic arietitids and harpoceratids in the rich collection of Cretaceous (Albian) ammonites from Angola of The American Museum of Natural History.[1]

These observations brought to mind the controversy which arose in 1908 between Gustav Steinmann on the one hand and C. Diener, my unforgettable teacher, and J. F. Pompeckj on the other. The former assumed the direct descendance of some ammonite genera from chronologically far distant ancestors, e.g. of the Cretaceous Pseudoceratites from the Triassic Ceratites. Steinmann (1908, 1909a, 1909b) claimed this to be "persistence of races," but he was refuted by Pompeckj (1910) and, particularly, by Diener (1908, 1909), who proved these resemblances to be merely morphologic ones without any phylogenetic significance. Referring to a previous observation by Neumayr,[2] Diener (1909, p. 418) emphasized that they were due merely to the fact that

> the same types of sculpture and suture repeat themselves in quite separated lineages of ammonites, since the number of possible variations is a limited one.

Although Steinmann's conception was thus soon proved to be erroneous, we are

[1] Hereinafter referred to as "AMNH."

[2] 1889, p. 113: " . . . dass nämlich Formen von ausserordentlicher habitueller Aehnlichkeit in augenscheinlich nicht näher miteinander verwandten Gruppen auftreten. . . . Es hat sich ergeben, dass z. B. innerhalb der grossen Abtheilung der Aegoceratiden in den verschiedensten Stämmen immer dieselben Sculpturtypen der Schale auftreten, und dass jeder dieser Sculpturtypen fast immer von einer ganz bestimmten Gestaltung des Gesamtumrisses und sehr oft auch der Entwicklung der Kammerscheidewände begleitet ist . . . " ibid., p. 114: "Man kann die Hauptmasse der hieher gehörigen Formen in eine geringe Anzahl solcher Typen eintheilen, welche in den verschiedensten Gruppen immer wiederkehren. Ein solches Verhalten lässt nur eine einzige Art der Erklärung zu, dass nämlich der Organisation und Constitution dieser Tiere entsprechend nur eine beschränkte Zahl von Abänderungsrichtungen in den genannten Merkmalen gegeben und möglich ist, welche, allerdings mit unendlicher Mannigfaltigkeit im einzelnen, immer wiederkehren, je nach der mechanischen Einwirkung, welche auf den Organismus stattfindet."

indebted to his error for some striking examples of this phenomenon, which it is here proposed to call "recurrence of morphologic types" instead of using his misleading term "persistence of races." Some of the similarities seen in Steinmann's (1909b) figures 1–12 in which Triassic ammonites are compared with Cretaceous, or uppermost Jurassic ones, are striking indeed and include even the sutural characters; although careful study of the suture lines proves that they do not agree quite as perfectly as Steinmann, obsessed by his idea, believed.

Another interesting homoeomorphy between some large ammonite shells of the Cretaceous Ootatoor group of Southern India and some *Ptychites* of the Austrian Alpine Muschelkalk was first noticed by Stoliczka (1865, p. 125) and induced Kossmat (1895, p. 165) to create a new genus *Neoptychites* for the former. This homoeomorphy can best be seen by comparing Kossmat's (1895, pl. 21) figures of the type of *Neoptychites telinga* (Stoliczka), previviously figured by the latter (1865, pl. 62), with Mojsisovics' (1882, pl. 68) figures of *Ptychites reductus* Mojsisovics. Kossmat, however, was much more cautious than Steinmann in regard to the establishment of phylogenetic relations, stating (1895, p. 167)

> that the interval between Muschelkalk and Middle Cretaceous, separating these genera, was too huge to be bridged.

By sifting some of the ammonitological monographs of the last six decades or so I have arrived at the conviction that such examples of homoeomorphies might be increased almost ad infinitum. Three of these examples are shown in plate 93, figures 1–7; particularly interesting is the occurrence of such peculiar characters as the flaring ribs, pointing obliquely backward in ventral view, in both the Oolite and the Gault member of the couple depicted in figures 5–7 of this plate.

Two Liassic families, the Arietitidae and the Harpoceratidae, are particularly noteworthy from the point of view of this study, as both of them have forerunners in the Triassic as well as stragglers in the Cretaceous (both these words not to be understood in a phylogenetic sense.)

Three Triassic genera have produced *Arietites*-like forms: *Balatonites*, a species of which was named *B. arietiformis* by Mojsisovics (1882, p. 85, pl. 38, figs. 1, 2); *Tropiceltites* Mojsisovics (1893, pp. 369–392, pl. 119, fig. 19; pl. 120, figs. 9–21, 23–28; pl. 121, figs. 36, 37, 39–44; pl. 123, fig. 3; pl. 128, figs. 3, 5, 10–12, 16, 19, 20; pl. 129, figs. 3–5; pl. 195, figs. 6, 7; pl. 197, fig. 1), displaying a rich array of such forms, and *Tropigastrites* J. P. Smith (1914, p. 25). Representatives of all three of these genera are shown in plate 93, figures 8–15. There is an amazing resemblance between the *Tropiceltites* seen in figures 12 and 13 of this plate (*T.* ind. ex affin. *T. subgeometrici* Mojsisovics, 1893, p. 375, pl. 120, fig. 10, and *T. rotundus* Mojsisovics, 1893, pl. 120, fig. 9) and some equally small *Arietites* recorded by Wähner from the Lower Lias of the Northeastern Alps, e.g., *A. semicostulatus* Reynès (in Wähner, 1884, p. 212, pl. 27, especially figs. 10, 11; reproduced in pl. 93, figs. 16, 17). It may be worth noting that *Tropigastrites* does not fully achieve the *Arietites*-type: Meek's (1877) first side view of *T. halli* (named by him *Clydonites laevidorsatus*), as reproduced by J. P. Smith (1914, pl. 14, fig. 7), looks very *Arietites*-like indeed, but this may be due to some exaggeration of the draftsman. Therefore, one of J. P. Smith's (1914, pl. 17, fig. 5) side views of his genotype, *T. trojanus*, is also shown in plate 94, figure 6, beside Meek's protograph (pl. 93, figs. 14a, b); in the former species the venter just "approaches," as J. P. Smith puts it, "to the formation of a keel"; ventral furrows, as found in the most characteristic *Arietites*, are missing. The same is also true of Wähner's early Liassic dwarf forms of the latter genus, as seen in plate 93, figures 16, 17.

That some Albian ammonites also imitate the arietitids was recognized by Neumayr as early as 1889 (p. 113); he pointed out that the "arietid-type" is also found in "*Schloenbachia*." Some forty years later, Dr. L. F. Spath, the best ammonite expert of our days, called one of his Pervinquierias from the English Gault *P. geometrica* (Spath, 1932, p. 395; 1933, pl. 44, fig. 1), thus alluding to its resemblance to *Arietities geometricus* Oppel, and he also named a species of the Albian of Angola, although based only on a fragment figured by Choffat (1888, p.

65, pl. 1, fig. 6) and another of the Gregory collection, "*Elobiceras*" *arietiforme*[3] (1922, p. 137, pl. 2, fig. 6). However, the similarity between Spath's holotype of *P. geometrica* and the specimen of *A. geometricus* from the English Lias with which he compares it (Wright, 1881, p. 284; 1878, pl. 1, fig. 4, under the name "*A. semicostatus* Young and Bird") is not as striking as that between the side views of another Liassic *Arietites, A. turneri* (Sowerby), as figured by Buckman (1921, pls. 221 A, B), and one of the varieties (var. *levicostata* Haas, 1942, pl. 20, figs. 4 a–c, text-figs. 9b, 10) of the aforementioned *P. arietiformis* (see pl. 93, figs. 18, 19). It is true that these two forms do not agree in ventral view, as the former is comparatively thick and shows two distinct ventral furrows, whereas the latter is slender and has a fastigate venter. In plate 94, figures 3b and 5, however, whorl sections of a Liassic arietitid, *Arietites* (*Aetomoceras?*[4]) *scipionanus* (d'Orbigny), (after Wright, 1879, pl. 13, figs. 1–3), and of an Albian pseudoarietites,[5] viz. one of the AMNH's specimens of the typical *Pervinquieria arietiformis* from Angola, can be seen which fully agree with each other. As seen in the same plate, the side views differ merely by the fact that the costation of the Liassic form is denser and stiffer; however, there is observable, on the anterior parts of the outer whorls of both specimens, the same decrease in both density and stiffness and also in sharpness of the ribbing.

Here it might be the place to broach a question which already may have occurred to the reader: If agreement of two forms of quite different geologic ages, as seen in some of the figures accompanying the present paper, comprehends every character, should they not be united in taxonomy, at least generically? Whoever shares the writer's belief that the genus and the higher taxonomic units can be but morphologic assemblages, as morphologic features can be seen, whereas phylogenetic relations can only be inferred—whoever believes so, has to answer this question in the affirmative; provided, of course, that there is really agreement in all characters. However, in the cases of *Ammonites scipionanus* and *Pervinquieria arietiformis* the suture lines (pl. 94, figs. 3c and 5) are quite different in both genera: while, in the Liassic one, just the margins of saddles and lobes are indented, both saddles and lobes are much more intersected in *P. arietiformis*, whose suture line is altogether more elaborate. This fact seems to give another evidence of the importance of knowing at least the general characters of the suture line before even a generic determination of an ammonite from a new horizon or locality is ventured.

In the Albian fauna of Angola, from which all these Cretaceous forms are taken, there also occur pseudoarietites which, in in their general habitus, far deviate from *Pervinquieria arietiformis*. For example, *P. bassleri* Haas (1942, pl. 13, figs. 5a–e, pl. 15, figs. 2a–d), a much smaller form, has a depressed whorl section and is much sturdier than the former species, and it has, furthermore, a more robust and less regular ribbing. However, there are also Liassic forms which closely resemble this type. In figures 1 and 2 of plate 94 it can be compared with "*Murleyiceras*" *forte* Buckman (1921, pl. 245), which is, despite its rare generic name,[6] an *Arietites* from the Upper English Lias. It is, no doubt, less thick than the Cretaceous form and its venter differs, particularly as to costation, but in general appearance both forms are very similar, especially in side view.

A comparison of the large, more or less slender discs, with a regular costation, of both the Liassic arietitids and the Albian

[3] Generically referred to *Pervinquieria* by the writer (1942, pls. 18, 19, 20, figs. 1, 2; pl. 22, figs. 2–7) and, therefore, hereinafter quoted as *P. arietiformis* (Spath).

[4] This genus was established by Hyatt (1900, p. 575) and referred by him to the Oxynotidae, one of the families of his group of the "Arietida" (1900, p. 574); Roman (1938, p. 102), however, refers it to Haug's family Polymorphidae.

[5] This term is used, throughout this paper, analogously to Hyatt's (1903) expression "Pseudoceratites," without any reference to Frech's (1902, p. 63) Upper Devonian genus *Pseudarietites*.

[6] In his "Type Ammonites," particularly in the later volumes of this monograph, Buckman created a new generic name for almost every species. In the alphabetic list of genera (vol. 7, parts 71, 72, 1930, p. 51) 407 genera are listed, most of which are new. However, only a few of these generic names seem to have been used by other authors, and hardly any of them have been generally accepted.

pseudoarietites, figured in plate 93, figures 18, 19, and plate 94, figures 3–6 with the small, sturdy, less regularly costate types seen in plate 94, figures 1, 2, a Liassic one on the left, a Cretaceous one on the right, appears to furnish the best illustration of the following statement made in the abstract: "In some cases even the same differentiation of certain types as to their whorl sections, degree of involution, character of costation, etc., recurs within groups separated by wide time intervals."

The harpoceratids also have a fore-runner in the Upper Triassic, namely the genus *Discotropites* Hyatt and Smith (1905, p. 61), first included by Mojsisovics (1893, pp. 283 ff.) in Hyatt's (1900, p. 554) genus *Eutomoceras*.[7] In plate 94, figures 7–12, a specimen of the genotype of *Discotropites, D. sandlingensis* (von Hauer) (Mojsisovics, 1893, p. 285, pl. 130, figs. 11–13; pl. 131, figs. 1–11; Hyatt and Smith, 1905, p. 63, pl. 35, figs. 1–12; pl. 36, figs. 1–26) is figured, along with a Middle Liassic *Grammoceras, G. dilectum* Fucini (1900, p. 50, pl. 11, figs. 2, 3; 1904, p. 278, text-fig. 106, pl. 18, figs. 11,[8] 12, here under the generic name "*Harpoceras?*)" from the Apennines, and the holotype of *Neoharpoceras conditum* Haas (1942, pl. 36, figs. 2a–c, text-fig. 17) from the Albian of Angola. The resemblance of *Ammonites sandlingensis* von Hauer to *Harpoceras* has already been stressed by Hyatt and Smith (1905, p. 64), whereas Mojsisovics (1893, p. 284) mentioned merely its similarity to *Oxynoticeras*. The generic name *Neoharpoceras* was created by Spath (1921, p. 282, 1st footnote),[9] who thus gave another proof of his keen observation of forms. It seems very interesting indeed to compare the three forms shown in plate 94, figures 7–12. In some regards, for instance in the less sigmoidal course of the ribs, in the height and sharpness of the keel and in the comparatively high degree of involution the Cretaceous form seems to resemble the Triassic one even more than the Liassic one, despite the greater time interval. Here too, as in the arietitids and pseudoarietites, the suture lines of the three forms shown on the same plate are very different from each other, thus yielding reliably distinctive generic characters. *Discotropites* and *Neoharpoceras* also have a fine spiral striation in common, which is, however, more clearly visible in the ventral view of *N. conditum* (fig. 12b) than in its side view (fig. 12a). It may be added that this feature is much more developed in another Albian genus from Angola, *Elobiceras* Spath (1921, p. 306; 1922, pp. 103–104, 132 ff., pls. 1, 2; see also Haas, 1942, text-figs. 11–13, pls. 23, figs. 2–5; pls. 24–30, 31, figs. 1–4; pl. 33, fig. 1; pl. 35, figs. 1–10).

It has, in the course of this report, repeatedly been emphasized that no phylogenetic significance is assigned to the similarities here dealt with. It might, moreover, be advisable to supplement this purely negative statement from the positive side, by recording what else we know, or believe to know, about the origin of the groups concerned.

The Arietitidae of the Lias do not descend from the highly specialized forms of the Triassic families Ceratitidae (*Balatonites arietiformis*) and Tropitidae (genera *Tropiceltites* and *Tropigastrites*) which assume a similar habitus (cf. Schindewolf, 1940, p. 230). Since Hyatt's (1889) days they have been derived rather from the unkeeled Psiloceratidae of the lowermost Lias.[10] Nor can the Harpoceratidae be derived from the Triassic *Discotropites*, as Steinmann (1908,

[7] The resemblance between *Himavatites canadensis* McLearn (1940, p. 115, pl. 3, fig. 3) and *Polyplectus discoides* (Zieten) (in Roman, 1938, p. 119, pl. 10, fig. 105) is confined to the side views, which are almost indistinguishable, whereas the ventures are quite different: In the Triassic form it is "almost flat" and bounded by "angular, ventral shoulders," while in the Upper Liassic one it is sharpened almost to a knife edge.

[8] The side and frontal views of this figure are reproduced by Roman (1938, pl. 10, fig. 103) as representative of the genotype of *Protogrammoceras* Spath (1913, p. 550), recognized by Roman merely as a subgenus of *Grammoceras;* in his text, however, Roman designates *Harpoceras ugolinii* Fucini (1904, p. 277, pl. 18, fig. 10) as the subgenotype, erroneously believing this species to be depicted in his plate 10, figure 103. This confusion is still increased by the fact that some parts of Roman's subgeneric diagnosis obviously refer to *G. dilectum*, whereas others are almost a translation, though a mistaken one ("più sviluppate" is translated "peu développées," instead of "plus développées"), of Fucini's description of his "*Harpoceras?*" *ugolinii*.

[9] See also 1922, p. 105. Later (1934, p. 459) Spath "relegated" *Neoharpoceras* "to the rank of a subgenus of *Prohysteroceras*."

[10] Cf. Roman, 1938, p. 61, table.

p. 192) attempts to do. According to him, in Diener's (1909, p. 423) words,

"*Discotropites* is not allowed to die out, but has to persist in *Harpoceras*."

On the contrary, Haug (1885) and Geyer (1893) have carefully shown that the Harpoceratidae originate from the Arietidae, with which they are linked by many transitions. This opinion has quite generally been accepted since (Diener, 1908, p. 578, 1909, pp. 422, 423; Roman, 1938, p. 61, table). In the same way, an attempt to derive the Cretaceous pseudoarietites from the Liassic *Arietites*, or the Cretaceous *Neoharpoceras* from the true *Harpoceratidae*, would go far astray. We know that the former originate, polyphyletically, from the earlier Cretaceous genus *Dipoloceras* and, probably, at least in part, also from the peculiar little *Neokentroceras*, and that the latter descend, via *Prohysteroceras*, from *Pervinquieria* (see Haas, 1942).

However, there is a fascinating analogy between the transition of the Liassic Arietitidae into the Harpoceratidae on the one hand and that of the Albian *Pervinquieriae* into *Prohysteroceras* and *Neoharpoceras* on the other. Both these evolutionary changes appear to proceed, quite gradually, along the same lines of definite anagenetic trends, namely from rather evolute, stout shells with coarse and stiff costation to more involute and discoidal ones, whose whorls increase more rapidly in height and become fastigate ventrally, with finer and more sigmoidal costation and with more elaborate suture lines. For details reference is made to Haas, 1913 (pp. 134–140), for the Liassic forms and to Haas, 1942, for the Cretaceous ones. To prevent possible objections, it is explicitly admitted that no general validity can be claimed for the aforementioned anagenetic trends: for example, "familes that are smooth-shelled in the Lower Triassic often become rough-shelled in the Upper Triassic" according to Hyatt and Smith (1905, p. 27), and, within the Liparoceratidae, involute forms precede more evolute ones according to Spath (1938, p. 2).[11] However, in the writer's opinion careful investigation might uncover many more examples of such recurring evolutionary cycles as that one just discussed.

Finally, emphasis is laid on the fact that thoughts similar to those expressed in this paper have been voiced not only long ago by Neumayr and Diener, as quoted in the introductory part of this report, but also quite recently by Schindewolf, who, in his study on convergences (1940), speaks of "iterative Wiederholung stets gleicher Entwicklungsabläufe" ("iterative repetition of always the same evolutionary course") and asserts "parallelle Entwicklung in zeitlichem Nacheinander und auf einer jeweils höheren Grundlage" ("parallel evolution in chronological sequence on a higher and higher level"), and by another German student, W. Zoch (1940), who, in a study on the phylogeny of the Belemnites of the Suabian Dogger, states a principle of "Wiederholung der Gestaltungsmotive" ("repetition of trends of forming forces").

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ADDENDUM

This paper was submitted with the expectation that it would not be published before a larger one by the same author (Haas, 1942), in which two new species and one new variety herein referred to are described. Publication of the larger paper has been unexpectedly delayed, though it is still hoped that it will appear in 1942. As the plates for the present paper had already been printed before the delay was reported, it was impracticable to grant the author's request to postpone its publication. Descriptions of the new forms are therefore appended.—EDITOR

PERVINQUIERIA ARIETIFORMIS var. LEVICOSTATA Haas, n. var.

Plate 93, figures 19a, b

Differs from the typical form by its more closely spaced, narrower, stiffer ribs, which almost entirely lack spiral striation.

[11] On the other hand, Trueman's (1922, p. 142) statement that "the normal order of appearance of ornamentation in Ammonites, as in many other groups is (a) striae (b) costae (c) tubercles" is certainly much too general. In all the sculptured forms of the Albian of Angola recently studied by the writer (1942) the order is just the reverse.

PERVINQUIERIA BASSLERI Haas, n. sp.
Plate 94, figures 2a, b

Wheel-shaped, almost fully evolute, with a strong keel, accompanied by rather broad furrows. Whorl section transversely rectangular, later trapezoidal, always wider than high. Ribs strong and prominent, single as a rule, rursiradiate, continuing on the venter. Prominent umbilical tubercles, external tubercles, and, in maturity, up to four indistinct lateral nodes. Suture line simplified.

NEOHARPOCERAS CONDITUM Haas, n. sp.
Plate 94, figures 12a–d

Discoidal, slender, rather involute. Whorls increasing rapidly in height, with high, lancetiform section and high, strong keel. About 85 broad sigmoidal ribs per whorl, doubling by bifurcation or intercalation on the inner half of the sides, with obsolete spiral ridges on and near the external shoulder. Suture line rather elaborate.

EXPLANATION OF PLATE 93

FIGS. *1a, b—Pseudogrammoceras latescens* (Simpson). *a*, Right side view; *b*, ventral view; both ×⅔. Yeovillian, Upper Lias. Peak, near Whitby, England. (p. 644)

2a, b—Dipoloceras rectangulare Spath, AMNH. no. 25097: 1. *a*, Right side view; *b*, ventral view; both ×⅔. Albian. Hanha, Angola. (p. 644)

3a, b—"Denckmannia" rudis (Simpson). *a*, Left side view; *b*, frontal view, "septicarina broken off" (Buckman, 1910, pl. 14); both ×⅔. Whitbian, Upper Lias. Near Whitby, England. (p. 644)

4a, b—"Pervinquieria nova spec. indet. no. 1," AMNH. no. 25156: 1. *a*, Right side view; *b*, whorl section; both natural size. Albian, Hanha, Angola. (p. 644)

5a, b—"Diplesioceras" diplesium Buckman, "an acmic Oppelid" (Buckman, 1920, pl. 177); genotype, holotype. *a*, Right side view; *b*, ventral view; both ×ca. 0.9. Vesulian, upper Inferior Oolite. Bridport, Dorset, England. (p. 644)

6, 7—Dipoloceras cristatum (Deluc MS.) Brongniart, var. *alata* Spath. *6*, Left side view of a septate small example; *7*, ventral view of a typical body chamber; both ×⅔. Lower Gault (bed VIII). Folkestone, England. (p. 644)

8a, b—Balatonites arietiformis Mojsisovics. *a*, Left side view; *b*, ventral view; both ×⅔. *Ceratites trinodosus* zone. Middle Triassic. Prezzo, Giudicarie, Italy. (p. 644)

9a, b—Tropiceltites multispiratus Mojsisovics. *a*, Left side view; *b*, frontal view; both ×⅔. (p. 644)

10a, b—Tropiceltites arietitiformis Mojsisovics. *a*, Right side view; *b*, ventral view; both ×⅔. (p. 644)

11a–c—Tropiceltites cunctator Mojsisovics. *a*, Right side view; *b*, frontal view; *c*, ventral view; all ×⅔. (p. 644)

12a, b—Tropiceltites rotundus Mojsisovics. *a*, Right side view; *b*, frontal view; both ×⅔. (p. 644)

13a, b—Tropiceltites ind. ex aff. *T. subgeometrici* Mojsisovics. *a*, Right side view; *b*, frontal view; both ×⅔. (p. 644)

All *Tropiceltites* (figs. *9–13*): Carnic. Upper Triassic. Feuerkogel, Austria. (p. 644)

14a, b—Tropigastrites halli Smith. *a*, Right side view; *b*, frontal view; both ×⅔. Upper Middle Triassic. West Humboldt Range, Nevada. (p. 644)

15—Tropigastrites trojanus Smith. Right side view of a topotype; ×⅔. Upper Middle Triassic. West Humboldt Range, Nevada. (p. 644)

16, 17—Arietites semicostulatus Reynès. *16a*, Right side view; *b*, frontal view; both somewhat reduced. *17*, another specimen; *a*, right side view; *b*, frontal view; both ×⅔. *Arietites rotiformis* beds, Lower Lias. Enzesfeld, Lower Austria. (p. 644)

18a, b—Arietites turneri J. de C. Sowerby. *a*, Left side view; *b*, ventral view; both ×½. Mercian, Lower Lias. Brislington, Somerset, England. (p. 645)

19a, b—Pervinquieria arietiformis (Spath), var. *levicostata* Haas, n. var. Holotype, AMNH. no. 25159. *a*, Left side view; *b*, ventral view; both ×½. Albian. Hanha, Angola. (p. 647)

1, 3, 5, 18, Reduced after Buckman, 1913, pl. 79, figs. 1, 2; 1910, pl. 14, figs. 1, 2; 1920, pl. 177, figs. 1, 2; 1921, pls. 221 A, 221 B, fig. 2.

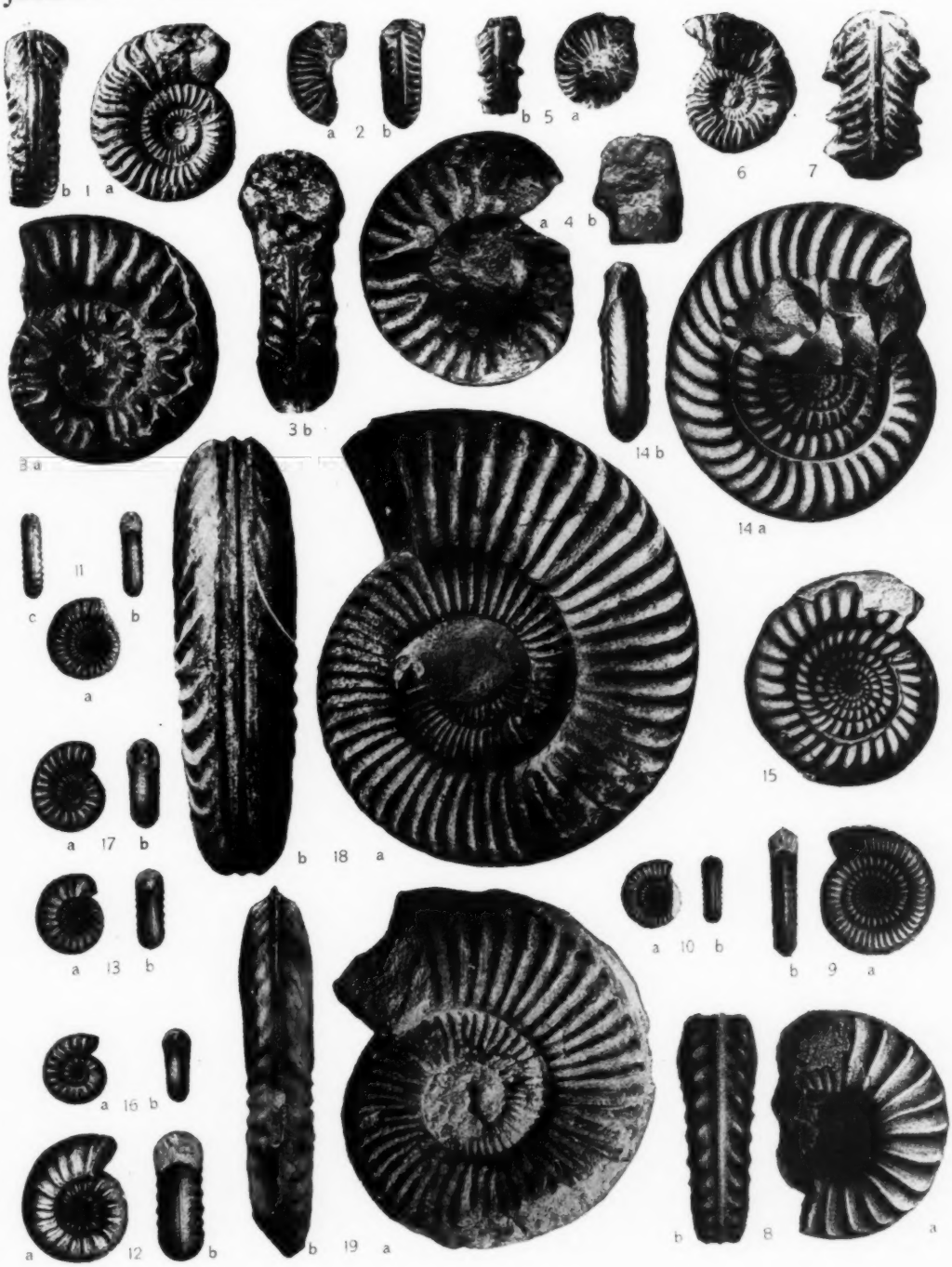
2, 4, 19, Reduced after Haas, 1942, pl. 1, figs. 4a, b; pl. 17, figs. 4a, d; pl. 20, figs. 4a, c.

6, 7, Reduced after Spath, 1931, pl. 35, figs. 12, 13.

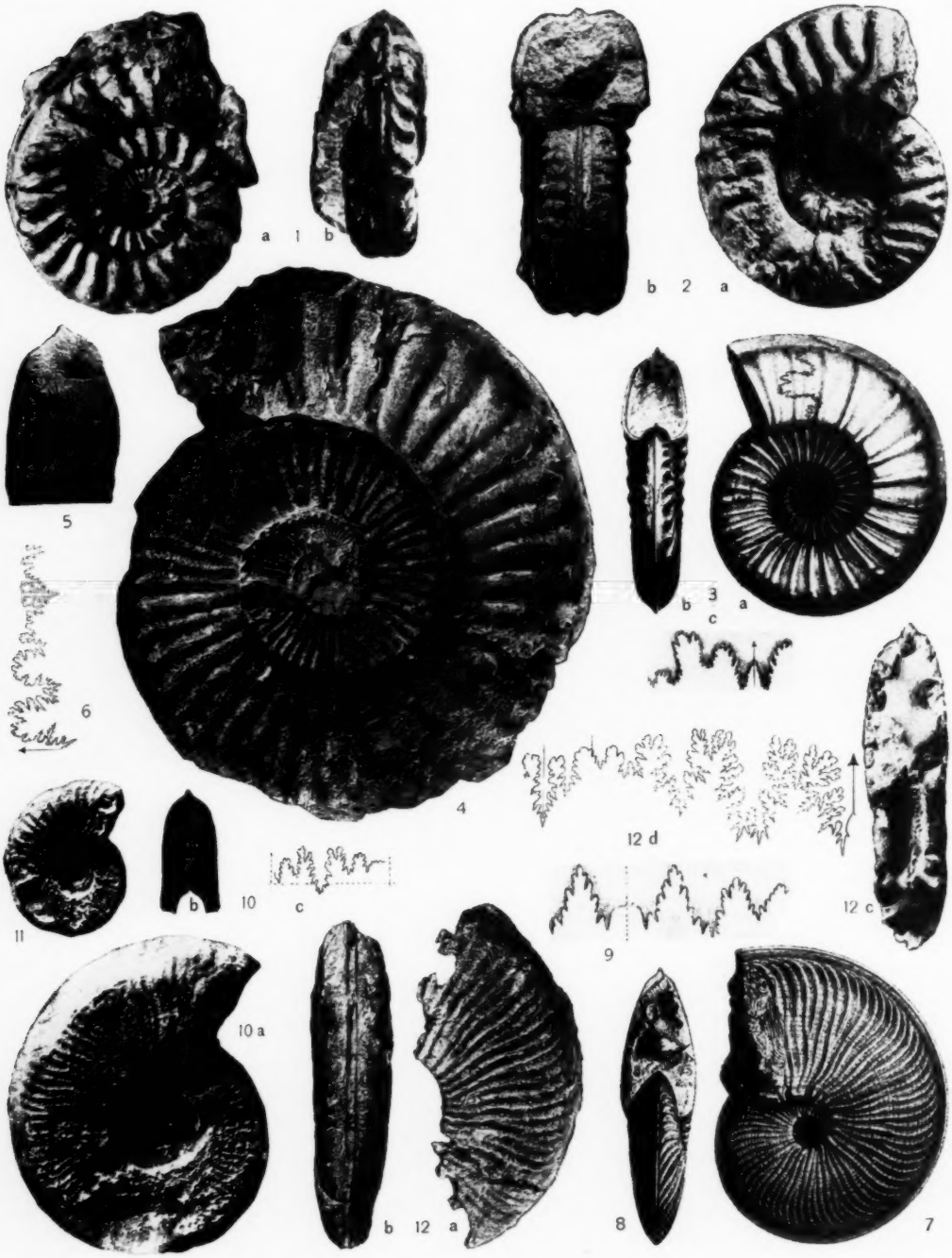
8–13, Reduced after Mojsisovics, 1882, pl. 38, figs. 1a, b; 1893, pl. 121, figs. 44a, b, 39a, b, 43a–c; pl. 120, figs. 9a, b, 10a, b.

14, 15, Reduced after Smith, 1914, pl. 14, figs. 7, 7a (reproductions of Meek's protographs); pl. 17, fig. 5.

16, 17, Reduced after Wähner, 1886, pl. 27, figs. 10a, c, 11a, c.



Haas, Mesozoic Ammonites



Haas, Mesozoic Ammonites

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EXPLANATION OF PLATE 94

FIGS. *1a, b—"Murleyiceras" forte* Buckman, holotype, *a*, Right side view; *b*, ventral view; both ×1. Whitbian, Upper Lias. Dumbleton, Glos., England. (p. 645)

2a, b—Pervinquieria bassleri Haas, n. sp., holotype, AMNH. no. 25153: 1. *a*, Right side view; *b*, frontal view; both ×1. Albian. Hanha, Angola. (p. 648)

3a–c—Arietites (*Aetomoceras?*) *scipionanus* (d'Orbigny). *a*, Left side view; *b*, frontal view; both ×4/15; *c*, suture line, somewhat reduced. *Arietites bucklandi* zone, Lower Lias. Semur, Côte d'Or, France. (p. 646)

4–6—Pervinquieria arietiformis (Spath). *4*, Left side view of largest disc, AMNH. no. 25157: 6, ×4/15; *5*, whorl section of AMNH. no. 25157: 10, ×½; *6*, suture line of AMNH. no. 25157: 2, ×ca. ¾. Albian. Hanha, Angola. (p. 644)

7–9—Discotropites sandlingensis (von Hauer). *7*, Left side view; *8*, frontal view of another specimen; *9*, suture line of a third; all ×⅔. Carnic, Upper Triassic. Vorder-Sandling and Raschberg respectively, Austria. (p. 646)

10, 11—Grammoceras (*Protogrammoceras*) *dilectum* Fucini. *10a–c*, the specimen figured by Roman (1938, pl. 10, fig. 103) as representative of the subgenotype of *Protogrammoceras* Spath; *a*, right side view; *b*, whorl section; *c*, suture line; all ×⅔; *11*, right side view of a young individual, ×⅔. Middle Lias. Monte di Cetona, Central Apennines, Italy. (p. 646)

12a–d—Neoharpoceras conditum Haas, n. sp., holotype, AMNH. no. 25191. *a*, Left side view; *b*, ventral view; *c*, sectional view; all ×⅔; *d*, suture line, about ×1. Albian. Hanha, Angola. (p. 648)

1a, b, After Buckman, 1921, pl. 245, figs. 1, 2.

2b, 4–6, 12, Reduced after Haas, 1942, pl. 15, fig. 2c; pl. 19. fig. 2a; pl. 20, fig. 10; pl. 22, fig. 2b; pl. 36, figs. 2a–c; text fig. 17.

3a–c, Reduced after Wright, 1879, pl. 13, figs. 1–3.

7–9, Reduced after Mojsisovics, 1893, pl. 131, fig. 8; pl. 130, figs. 11b, 12.

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ARTHRODIRAN FISH PLATES FROM THE ENFIELD FORMATION (UPPER DEVONIAN) OF NEW YORK

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ABSTRACT—A large median-dorsal plate and other fragmentary plates from a single individual are identified as *Glyptaspis abbreviata* Eastman, which is made the type of the new genus *Deirosteus*, related to *Holonema* Newberry. *Holoptychius omaliusii* Agassiz from the Middle Devonian of Belgium is also placed in the new genus.

INTRODUCTION

THE UPPER DEVONIAN Enfield formation lies above the marine Ithaca formation of central New York and its continental equivalent, the Oneonta formation, to the east. The Oneonta is well known for the relative abundance in certain horizons of dissociated fish plates, spines, teeth, and scales, mostly fragmentary but occasionally fairly complete, many of them yet undescribed. In the Enfield and Ithaca formations, however, though fossil invertebrates are quite common, fish remains are very rare. From the Enfield east of Seneca Lake only two specimens have been reported, the head plate of a dinichthyid and a dental plate of *Dipterus* (*D. ithacensis* H. S. Williams, 1882, pp. 192–193)—both from the lower beds of the formation near Ithaca[1] (Romer and Grove 1935, p. 825).

The discovery in the basal part of the Enfield, in 1939, of a very large and nearly entire median-dorsal plate of an arthrodire related to *Holonema*, associated with fragments of other plates of the same individual, is therefore of more than passing interest.

LOCALITY AND HORIZON

The specimens (Paleontological Research Inst. no. 5945) were found in a single block in a ledge of massive, blue-green, slightly calcareous, fine-grained sandstone about 3 feet thick. The ledge forms a little waterfall at an elevation of about 890 feet in Williams Brook, a stream flowing into the head of Cayuga Lake from the west in Tompkins County, central New York. The sandstone, containing no other fossils except occasional *Stropheodonta mucronata* and bits of carbonized wood (*Callixylon?*), evidently is the Hatch sandstone member at the base of the Enfield referred to by Caster (1933, p. 201) in his classification of the Upper Devonian of the Ithaca region. That this sandstone lies within the lower Enfield at the Williams Brook section is also indicated by an outcrop of the second *Reticularia laevis* zone, which marks the top of the underlying Ithaca, downstream 45 feet below the outcrop at the little falls and about 465 feet above the *R. laevis* zone at the top of the Sherburne formation a little above the level of Cayuga Lake.

PRESERVATION AND PREPARATION

The plates are fairly well preserved, dark-brown except where bluish from exposure to weathering, and difficult to extract from the tough matrix. The large median-dorsal plate had for some time formed the lip of the falls, and more than half of the bone was gone, leaving, however, a good external mould. It lay in the rock with the external surface downward. The other plates were irregularly distributed close to and just beneath it, rarely in a horizontal position and none in direct juxtaposition with another. The remaining bony material of the median-dorsal plate was removed in chips by chiseling or by etching with acid, leaving a nearly complete mould, from which a rubber cast was taken (pl. 95). One other large plate, probably of the lateral-dorsal trunk armor, also part of the waterfall crest, was almost entirely denuded of bone, but several more or less complete fragments

[1] Williams unfortunately gave no more precise locality for his material, and the horizon is uncertain. Romer and Grove, apparently on the basis of data from Chadwick, place it in the Enfield. Kindle (1896, p. 46) listed *D. ithacensis* as from the "lower Ithaca group and Ithaca shale.—H. S. Williams." The Ithaca shale of Kindle and of Williams lies at the base of the Ithaca formation.

of other plates were extracted and show the original bone surface. None of them shows signs of abrasion before burial, for the surfaces are sharp and clean, revealing the various types of coarse ornamentation typical of the *Holonemidae*.

PROVENANCE

The unworn but fragmentary condition of the plates and their close association suggest a mangled carcass drifting seaward, perhaps borne by flood waters from one of the great rivers debouching into the Enfield sea of the Penn-York embayment from Appalachia some 70 miles or so to the east, and finally sinking in a jumbled mass to the bottom.

DESCRIPTION OF THE MATERIAL

Median-dorsal (MD) plate. (Pl. 95).—This is the largest and most complete of the plates, and the only one the position of which in the external armor is certain. In outline it is rectangular, narrow for its length, measuring 41 cm. long with a maximum width of 21 cm. at the center of ossification 8 cm. from the posterior end, flat anteriorly, convex posteriorly, the convexity amounting to at least 2 cm. at the widest part of the plate. The thickest part is around the ossification center, where it measures 8 mm. The anterior margin is 17.5 cm. broad, evenly arcuate in outline, with subangular corners. The lateral margins are slightly convex, with a slight reentrant and bulge anteriorly, and with an unbroken curve posteriorly. The posterior corners are broadly rounded, and the margin is not preserved.

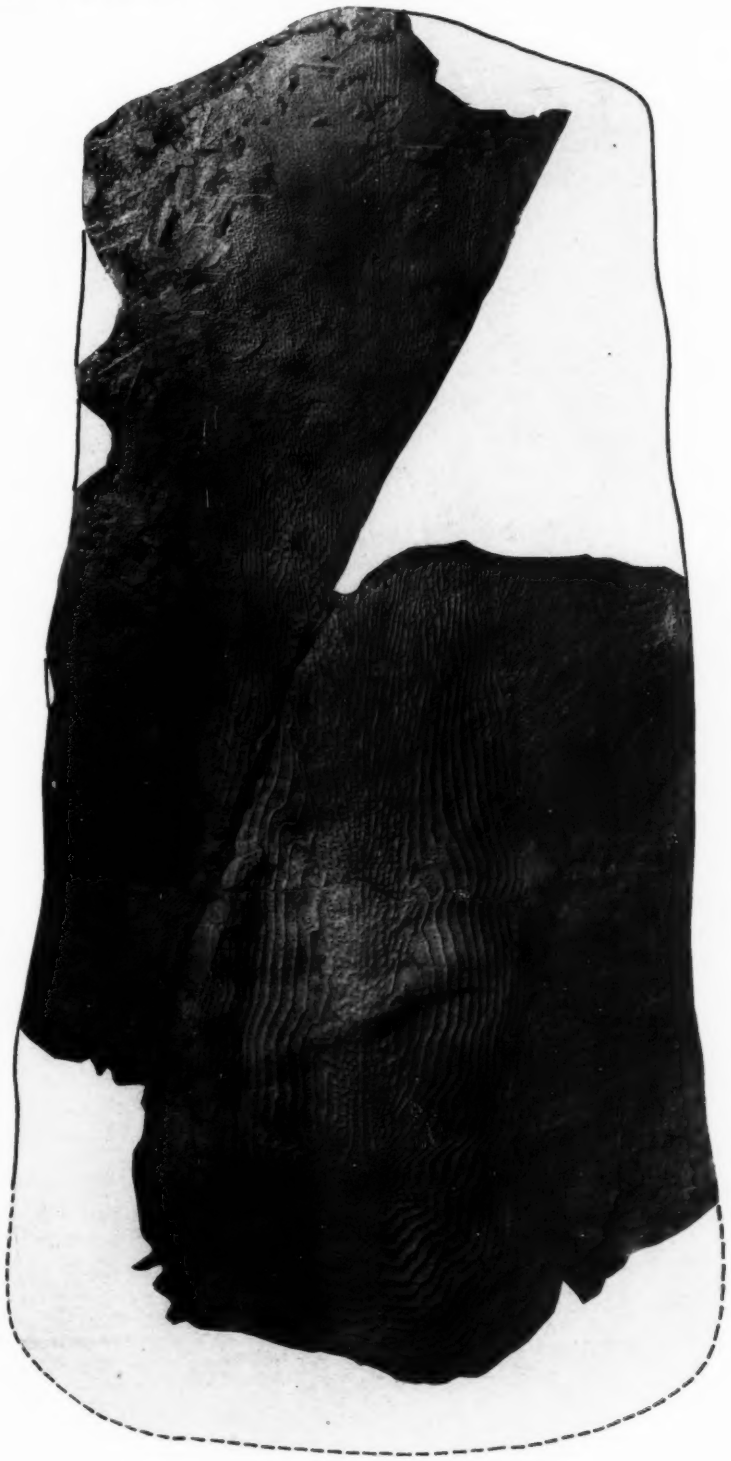
The internal surface is slightly concave posteriorly, with a faint median keel. At the posterior end there is a low central process, and doubtless there was a corresponding one at the anterior end, as in other holonemids (Obruchew, 1933, text fig. 5).

The external surface is highly sculptured by sharp ridges and rows of small acute stellate tubercles. The ridges are formed by fused rows of the tubercles. The center of the ornamentation resembles a club with its head over the center of ossification and its handle pointing forward. It consists of a single sharp median ridge extending to within 10 cm. of the anterior margin and terminating posteriorly in a cluster of concentrically aligned tubercles and discontinuous ridges. Around this central nucleus are concentric series of wavy or scalloped ridges 3 to 5 mm. apart, with broad shallow interspaces, many of which are studded by one or two irregularly scattered rows of tubercles. Towards the margin the ridges are more closely spaced and many are discontinuous. About 4.5 cm. from the margins they give way to close rows of tubercles, which in turn give way to a smooth strip about 5 mm. wide that forms the extreme edge of the plate laterally and posteriorly. The large ridges do not close anteriorly but are replaced by a wedge of fine diverging ridges and tubercles fanning out from either side of the "club" handle beginning about 5 cm. from the head and expanding to the sides in the anterior half of the plate. The entire anterior end is thus marked by rows of fine tubercles and interrupted ridges that converge posteriorly.

Five zones of ornamentation can then be discerned—the central "club," the lateral and posterior concentric wide-spaced ridge-and-tubercle system, the lateral and posterior submarginal tuberculate area, the smooth, narrow marginal zone, and the fan-shaped anterocentral zone of fine divergent ridges and tubercles.

No trace of sensory canals can be made out.

Other plates (pl. 96, figs. 1–3; pl. 97, figs. 1–3).—Two other plates, both incomplete but having the same ornamentation as the posterocentral zone of the *MD*, appear to represent parts of the dorsolateral armor. One (pl. 96, fig. 2; pl. 97, figs. 1, 2) is strongly arched transversely to its preserved length, which is more than 18 cm. It is subtriangular in outline, with one overlapping side intact, and with a broad area along another side 2 cm. wide. This broad area, which was originally overlapped by an adjoining plate, bears a deep sensory groove along the whole length, so far as preserved, just within the overlapped area. Another sensory groove enters the opposite side of the same plate from the overlapping margin, and runs nearly parallel but slightly convergent to the other groove. The maximum thickness of the plate is 12 mm. The other plate (pl. 96, fig. 1) is a triangular piece of a slightly arched element with one complete and



Deirosteus abbreviatus (Eastman)
Rubber cast of median-dorsal plate, × ½, from the lower part of the Enfield formation, Tompkins County, New York

Wells, Upper Devonian Fish Plates

nearly straight margin 16 cm. long and with another slightly convex margin meeting the first at an angle of slightly more than 90°, and extending 7 cm. from the corner. It is traversed by a deep sensory groove, which begins about 1 cm. in from the edge of the center of the longer side, bends at the center of the plate, and ends before it reaches the edge of the other side at the broken-off corner. The longer side is sharply differentiated from the rest of the plate and evidently was overlapped by a fairly thick plate (*MD?*) whereas the other edge is but slightly set off with the ornamentation grading into it and may have been overlapped by a plate with a very thin edge such as the posterior edge of the anterodorsolateral plate (*ADL*). The plate is preserved as a natural mould of the exterior.

The ornamentation of acute vermiculate ridges with broad tuberculated interspaces of these two plates (pl. 97, figs. 1, 2) suggests that they adjoined the posterolateral part of the *MD*, since neither of them shows the fine close-set parallel broken ridges of the anterior portion of that plate.[2] The plate with the two overlapped areas may represent the anterior part of the right posterodorsolateral plate (*PDL*), with the broad overlapped area fitting under the posterolateral edge of the *MD*, the other by the posterior edge of the *ADL*. The sensory canal would then be the extension of the anterior lateral canal of the *ADL*. The *PDL* is the only normal arthrodiran plate bearing such a curved sensory groove with two overlapped margins opposite the ends of the groove. The *AVL* of the ventral shield often does have such a groove, but it is wholly an overlapping plate. The plate showing the two grooves is yet unplaced. It might be the hinder half of an elongate *ADL*, but if so would not correlate with the other one supposed to be the *PDL*.

Another plate (pl. 96, fig. 3; pl. 97, fig. 3) is very nearly complete. It is thin, triangular, arched, inequilateral, with rounded corners, with no overlapped sides, ranging in thickness from 1 to 3 mm., and measuring 11.5 by 10.5 by 8.5 cm. along the edges. The ossification center and center of ornamentation is about 2 cm. from the corner of the two shorter sides. The greatest curvature is through the ossification center parallel to the shortest side. The ornamentation is composed of highly stellate tubercles (pl. 97, fig. 3) concentrically arranged in more or less regular rows around the ossification center. Here and there rows of three or four tubercles are fused into short ridges. They are identical with those on other plates of the same specimen. No sensory grooves can be discerned. Its position is apparently in the lateral part of the cranial or trunk shields.

MICROSTRUCTURE

Thin sections were prepared from the bone of the *MD* and other plates for comparison with the fine structure of corresponding elements in other holonemids, particularly *Holonema rugosum* and *H. radiatum*. They are not wholly satisfactory because of crushing coincidental with compaction of the enclosing sandstone, but essential structures can be made out. The three layers characteristic of the arthrodirans are developed—the compact lamellar basal layer, the "spongiosa," and the upper tubercle layer (pl. 96, fig. 5). The lamellar basal layer is very thin compared with that of *Holonema*, although the plates are relatively thicker. The canal and mesh layers within the "spongiosa" are badly crushed and cannot be clearly differentiated. The upper layer is slightly crushed, but the canals are much smaller near the surface, and the outer lamellation is scarcely identifiable.

[2] One small rectangular fragment with no margins intact, found with these specimens shows the concentric looping ridges on one half, and the close-set interrupted ridges of the other half and may be a piece of the anterior part of the *ADL*.

EXPLANATION OF PLATE 96

FIGS. *1–3, 5—Deirosteus abbreviatus* (Eastman). Lower Enfield formation, Tompkins County, N. Y. *1, PDL?*, ×0.6 (rubber cast). *2*, Posterior part of *ADL?*, ×0.5. *3*, Unplaced subtriangular plate with tuberculate ornamentation, ×0.5 (rubber cast). *5*, Vertical thin section from anterior part of *MD*, ×6.

4—Deirosteus abbreviatus (Eastman). Sherburne formation, Schuyler County, N. Y. Right *PVL*, ×0.5, rubber cast of holotype, N. Y. S. M. 16029/1.

IDENTIFICATION AND RELATIONSHIPS

The large *MD* is quite unlike any other comparable plate now known from the American Devonian, as are also the fragmentary plates associated with it, with the exception of *Holonema* Newberry. There is, however, an important difference between the ornamentation of *Holonema* plates and those of the Enfield fish. In all true *Holonema* plates the sculpture of the external surface is essentially radiating, formed by usually continuous ridges that are broader than the interspaces between them, and which are usually centrally and peripherally anastomosed to form a network (pl. 97, fig. 4). Many of the broad ridges are covered, when well preserved, by very fine scattered tubercles; narrower ridges have single rows of tubercles. The ornamentation of the Enfield form, in contrast to that of *Holonema*, is more or less concentric and composed of isolated stellate tubercles and continuous ridges of fused tubercles, which are acute on top and separated by relatively broad interspaces.

The first type of ornamentation is found on the *PMV* plate, which is the holotype of *Pterichthys rugosus* Claypole[3] (1883, pp. 664–667, continental Chemung, Susquehanna County, Pa.), the genotype of *Holonema* Newberry (1889, p. 92); in another *PMV* collected by the writer from the "Green conglomerate" at the top of the Oneonta formation in Chenango County, New York; in the lateral ventral plate of *H. rugosum* figured by Newberry (1889, pl. 17, fig. 1) from the Chemung at Lawrenceville, Tioga County, Pa.; and in other plates (*ADL*, *EB*, and *MD*) of the same species collected by the writer from the Oneonta formation in Chenango County, N. Y. It is the ornamentation found on the two specimens described by Case in 1931 (p. 173, pl. 4, figs. 1, 2) from the Rockport limestone member of the Long Lake formation of the Traverse series at Rockport, Mich. These (the left *ADL* and *MB* with parts of adjoining *EB*s) represent an undescribed species very close to *Holonema rugosum*. And it is seen on the plate from the Middle Devonian Milwaukee limestone figured by Hussakof and Bryant (1919, pl. 32, fig. 1) and referred by them to *H. rugosum*, but which more probably is the same species as the Michigan form.

The plates of *H. radiatum* from the lower Upper Devonian (D_3^1) of Russia, described by Obruchew (1933), a species close to H. *rugosum*, show similar ornamentation. Only the internal surface of the *MD* of this form was figured by Obruchew (1933, pl. 7, fig. 3), and, as it corresponds to the inner surface of the large Enfield *MD* and to that of *H. rugosum* from the Oneonta beds mentioned above, it seemed desirable to compare their external appearance. Dr. Obruchew kindly sent the writer a photograph of the outer surface of his figured *MD*. It shows, although much worn, the same broad ridges and narrow interspaces as *H. rugosum* plates, while the plan of the ornamentation is similar to that of the Enfield *MD*.

The small *MD* of *Holonema eifeliense* (Kayser) from the Rhenish Middle Devonian, figured by Gross (1937, pl. 5, fig. 5) also has the same type and plan of ornamentation as *H. rugosum* and *H. radiatum*, but the anterior end (posterior of Gross) is elevated in a high crest quite unlike any other holonemids and probably represents a distinct, unnamed genus.

The second type of ornamentation, that shown by the Enfield plates, is shown on several plates previously described from the American Devonian, especially on the ventral plate (*AVL* according to Eastman, but the overlapped area on one side suggests the *PVL*) from the Geneseean Sherburne forma-

[3] This specimen was destroyed by fire at Buchtel (now Akron) College, in 1891. A plaster cast of it, however, figured by Claypole (1883, p. 667) and Newberry (1889, pl. 17, fig. 2), is now in the American Museum of Natural History (cast 5970).

EXPLANATION OF PLATE 97

FIGS. *1–3*—*Deirosteus abbreviatus* (Eastman). Lower Enfield formation, Tompkins County, N. Y. *1, 2*, Surface ornamentation of *ADL?*, ×6. *3*, Surface ornamentation of small lateral trunk plate, ×6.

4—*Holonema* n. sp. Traverse series, Rockport, Mich. Surface ornamentation of *ADL*, ×6. From plaster cast of rubber mould of U. M. 13043.

1

2

3

4

Wells, Upper Devonian Fish Plates

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tion of central New York, to which Eastman (1907, p. 147, pl. 13) gave the name *Glyptaspis abbreviata*. Later this species was referred to *Holonema* by Hussakof and Bryant (1919, pp. 102–103), who showed it not to pertain to *Glyptaspis* Newberry, a Cleveland shale fish. The writer has studied a rubber cast of the holotype of *G. abbreviata* (N.Y. S.M. No. 16029/1) (pl. 96, fig. 4) and has little doubt that it belonged to the same species as the Enfield *MD*.

Hussakof and Bryant (1919, pp. 102–103, pl. 31) also referred to *H. abbreviatum* a thin, flat, rectangular plate from the Geneseean West River shale of Erie County, N. Y., bearing a sensory groove (not mentioned by them), which has the ornamentation of concentric rows of isolated tubercles and short rows of fused tubercles. Under *Dinichthys* they (1919, p. 60, text fig. 18, pl. 19, fig. 2) also described from the Geneseean conodont bed of Erie County a sizeable *MB* that has the shape of the *MB* of *Holonema radiatum* and the *Holonema* from Michigan previously referred to in this paper, but whose ornamentation consists of an anterior wedge of radiating rows of tubercles and lateral concentric rows of tubercles having the general aspect of the anterior ornamentation of the Enfield *MD*. This specimen probably pertains to the same species.

Obruchew (1933, pp. 108–111) has recognized two other holonemid genera, *Gyroplacosteus* and *Megaloplax*, based upon imperfect material from the lower Upper Devonian of Russia. *Megaloplax*, with one species, *M. marginalis* (Eichwald), is founded upon an imperfect and poorly preserved *MD* of moderate size, with surface sculpture of concentric ridges somewhat like those of the Enfield *MD*, but with the dorsal sensory canal developed. *Gyroplacosteus*, genotype *G. panderi* Obruchew, is distinguished by surface sculpture of very coarse rounded tubercles larger than their interspaces and often fused in short rows to form a sort of network.

For the fish represented by the plates from the Enfield formation, together with the plate described by Eastman as *Glyptaspis abbreviata*, a new generic name is proposed, on the basis of the distinctions from other holonemids already brought out:

Genus DEIROSTEUS[4] Wells, n. gen.

Genotype. *Glyptaspis abbreviata* Eastman, 1907. Sherburne formation, Geneseean stage, Upper Devonian, Valois (*olim* North Hector), Schuyler County, New York. Holotype, N.Y.S.M. No. 16029/1.

Holonemid arthrodires of large proportions, distinguished by the surface sculpture of the external shield, which is essentially concentric and consists of stellate tubercles and more or less continuous acute ridges separated by relatively broad and often tuberculated interspaces.

MD very elongate-rectangular, highly ornamented. No sensory canals.

PVL subquadrate, highly sculptured centrally.

MB triangular, like that of *Holonema*.

Parts of other plates (*ADL?*, *PDL?*) are known but are not yet placed with respect to the external armor.

Besides the holotype plate referred to above and the Enfield plates already described, the *MB* described by Hussakof and Bryant (Buffalo Museum no. E2008) and the unassigned (ventral?) plate figured by them (1919, pl. 31, Buffalo Museum no. E2025), are also included in the species, which thus ranges from the Geneseean into the Naplesian stage in the lower Upper Devonian of western and central New York.

Deirosteus also includes the following European Devonian species:

DEIROSTEUS OMALIUSII (Agassiz)

Holoptychius omaliusii AGASSIZ, *1844*, Mon. poissons, foss. Vieux Grès Rouge, p. 75, pl. 24, fig. 11.

Holotychius omaliusii, SMITH WOODWARD, *1891*, Cat. foss. fishes, Brit. Mus., vol. 2, p. 331.

Horizon and locality.—Poudingue de Caffiers, base of Middle Devonian (Givetian), Namur basin, Belgium.

Remarks.—Part of another *MD* of *Deirosteus* was figured nearly a century ago by Louis Agassiz in his classic work on the fishes of the Old Red Sandstone. He thought it represented part of a very large "ganoid" scale, perhaps one in the lateral-line system. The species seems never to have been mentioned since then except by Smith Wood-

[4] δειράς, a ridge.

ward, who referred to it as based upon an "indeterminable dermal plate." Comparison of Agassiz's figure with the *MD* of *Deirosteus* from the Enfield formation shows that the two are remarkably alike in size and ornamentation and probably in shape. The ridges of *D. omaliusii*, however, show more of a tendency to anastomose in nets than in *D. abbreviatus*.

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The writer gratefully acknowledges his obligations to the authorities of the Museum of the Buffalo Society of Natural Sciences, the Museum of Paleontology of the University of Michigan, the New York State Museum, and the American Museum of Natural History, who provided him for purposes of comparison rubber moulds or casts (plastotypes) of type or figured specimens of *Holonema* and *Glyptaspis*.

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GRAPTOLITES FROM THE ENGLEWOOD FORMATION (MISSISSIPPIAN) OF THE BLACK HILLS, SOUTH DAKOTA

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ABSTRACT—The description of three new species of *Dictyonema* from the basal shales of the Englewood formation of the Black Hills, South Dakota, places on record the second known occurrence of graptolites in rocks of Mississippian age in North America.

IN 1934 the junior author and several members of the Smith College Black Hills field party obtained a small number of fairly well preserved and nearly complete *Dictyonema* rhabdosomes on slabs of a purplish-gray calcareous shale, which has been referred by Darton (1925, p. 7) to the base of the Englewood formation. This shale crops out on the north side of the road, U. S. Highways 14 and 16, a mile northeast of the outskirts of Deadwood, S. Dak. The locality is a short distance above the junction of the two highways and is directly opposite the lower or western portion of a parking turn-out on the south side of the highway.

The recovery of nearly complete graptolite rhabdosomes is to be attributed entirely to the road widening operations, which were being carried on during the summer of 1934 on the highway. Subsequent visits to the same horizon by the junior author after intervals of two and three years revealed that the shale weathers rapidly upon exposure into small friable unfossiliferous fragments, and that even at a depth of 1 foot the weathering has removed most of the graptolites. Apparently several feet of shale must be removed before fresh material with reasonably good specimens can be obtained.

The stratigraphy of the outcrop was found to be as Darton had described it for this locality. In his discussion of the Englewood formation Darton (1925, p. 7) gives the following section along Whitewood Creek below Deadwood:

Pahasapa limestone.
Englewood limestone.

3. Gray slabby limestone, streaked with dark red and containing calcite druses.	40 feet
2. Purple shaly limestone with yellow stains.	
1. Shale—gray at top and yellow below.	10 feet

Many fossils were obtained by Darton from the Englewood, and among the localities specifically mentioned by him appears "in basal shales in road cuts about a mile north of Deadwood." This is apparently the same locality and horizon from which the graptolites were obtained, but no record of such forms appears in his faunal list, which was compiled by G. H. Girty. The only duplication which occurs in Lochman's collection is a specimen of a small broken *Lingula* sp., as with the exception of this single brachiopod the 1934 collection contained only specimens of *Dictyonema*.

DISCUSSION OF GRAPTOLITES

The graptolites from the Mississippian Englewood formation all belong to the genus *Dictyonema* and represent three species, here described as *D. dakotense*, *D. mississippiense* and *D. lochmannae*.

As the genus *Dictyonema* is the longest-ranging group of the graptolites, extending from the Cambrian to the Carboniferous, the occurrence of the genus itself gives no clue to the age of the rocks. Comparison of the species with others, before described, however, is very likely to afford valuable

clues. In the case before us *D. dakotense* Ruedemann, n. sp., has no pronounced relationship; it is comparable to *D. fragile* Bulman from the British Arenigian Sheloc Church beds, but has a coarser structure, and to the single known Carboniferous form, *D. blairi* Gurley, from the Choteau limestone of Missouri. From the latter it is distinguished by somewhat finer structure. *D. mississippiense* Ruedemann, n. sp., has the delicate structure of the rhabdosome and the crowded branches in common with some Silurian and Devonian species, but it is readily distinguished from them. Finally, *D. lochmannae* Ruedemann, n. sp., recalls both the late Cambrian or basal Ordovician *D. flabelliforme* (Eichwald) and the Mississippian *D. blairi* Gurley. It has the branches more closely arranged than the latter and also somewhat thicker branches, but may with larger collections of *D. blairi* Gurley prove to be identical with the latter.

SYSTEMATIC DESCRIPTIONS

Class GRAPTOLITHINA Bronn, 1846
Order DENDROIDEA Nicholson, 1872
Family DENDROGRAPTIDAE Roemer, 1897

DICTYONEMA DAKOTENSE Ruedemann, n. sp.
Plate 98, figures 1, 7

Rhabdosome of small to medium size, broadly flabelliform, rapidly expanding. Branches straight, narrow (0.2 mm. wide), numbering 12 in 10 mm., separated by intervals four times as wide as the stipes, bifurcating at intervals of about 7 mm. and at acute angles. Dissepiments straight to slightly concave, broad (as much as 0.3 mm.), closely arranged, numbering about 8 in 10 mm., forming quadrangular meshes, twice as long as wide. Thecae not seen in profile, and bithecae not observed. Thecae seem to number 30 in 10 mm.

Remarks.—*D. dakotense* Ruedemann, n. sp., is represented by a single specimen, which indicates a small fanlike growth, 28+ mm. long and 40+ mm. wide.

The relationships of the species are not pronounced. It is comparable in general aspect and dimensions to several forms, among them the British Ordovician *D. fragile* Bulman from the Arenigian Sheloc Church beds and the only known Mississippian form, *D. blairi* Gurley, from the Choteau limestone of Missouri. From the former it is distinguished by its somewhat coarser texture and from the latter by the finer texture.

Occurrence.—Mississippian, Englewood formation, on U. S. Highways 14 and 16, one mile northeast of Deadwood, S. Dak.

Types.—Holotype, C. L. 500.

DICTYONEMA LOCHMANNAE Ruedemann, n. sp.
Plate 98, figures 2, 3, 6, 8

Rhabdosome of large size, broadly conical or infundibuliform, the imperfect holotype measuring 9 cm. in length and 7.5 cm. in width. The original specimen probably had double the length of the fragment. Branches straight, of rigid appearance, relatively thin (0.3 mm. wide) parallel, widely spaced (8–9 branches in 10 mm.), dividing at frequent intervals (10 mm.) at very acute angles. The interspaces between the branches about 3 times as wide as the branches. Dissepiments about 0.2 mm. wide, straight transversal or convex forward, often also oblique, numbering 7–10 in 10 mm., forming quadrangular meshes, usually about twice as long as wide. Thecae little, projecting, with acute den-

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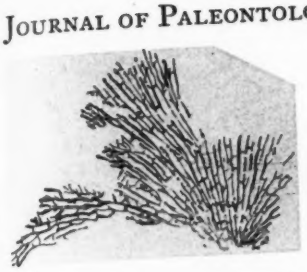
EXPLANATION OF PLATE 98

The types are all in C. Lochman's collection at Mt. Holyoke College, South Hadley, Mass. Duplicate material is in the Geology Department of Smith College, Northampton, Mass. All specimens from Mississippian Englewood formation, on U. S. Highways 14 and 16, 1 mile northeast of Deadwood, South Dak.

FIGS. *1, 7—Dictyonema dakotense* Reudemann, n. sp. *1*, Holotype, a small incomplete rhabdosome. ×1; *7*, detail of basal portion of rhabdosome, ×4, C. L. 500. (p. 658)

2, 3, 6, 8—Dictyonema lochmannae Ruedemann, n. sp. *8*, Holotype, a large but imperfect rhabdosome, ×1, C. L. 503. *6*, Paratype, a second large but incomplete rhabdosome, ×1, C. L. 502. *2, 3*, Paratype, a small fragment showing the coarseness of the structure, *2*, ×1; *3*, a detail of several central branches, ×4, C. L. 502a. (p. 658)

4, 5—Dictyonema mississippiense Ruedemann, n. sp. *4*, Holotype, a fragmentary rhabdosome, ×1; *5*, detail of the branches from left side of rhabdosome, ×4, C. L. 501. (p. 659)



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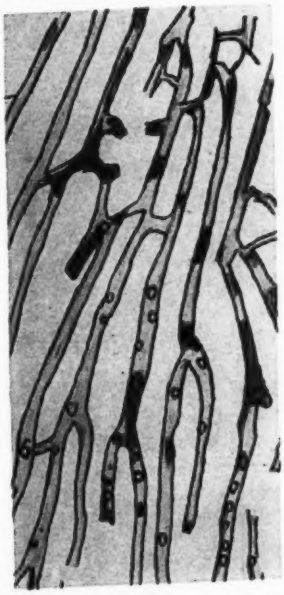

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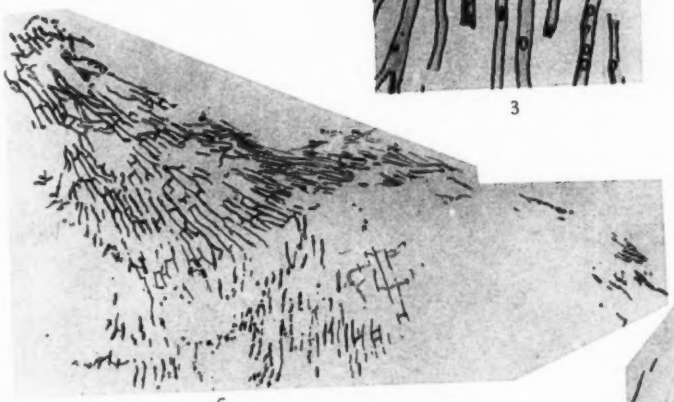

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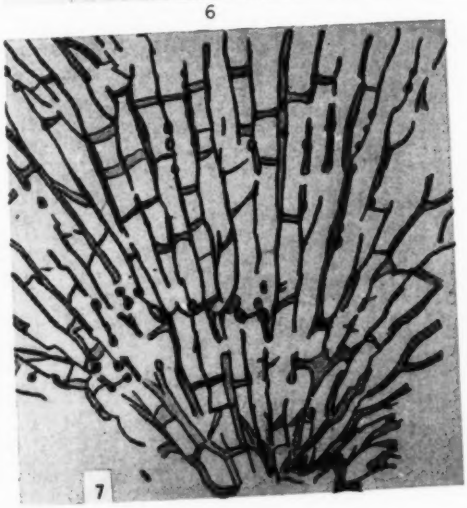

7

8

Ruedemann and Lochman, Mississippian Graptolites

UNIV. OF MICH.

ticles, numbering 16 in 10 mm. Bithecae not seen.

Remarks.—This species shows similarity to several forms. With its large conical rhabdosomes and fairly widely spaced branches, likewise in its general dimensions, it is very close to *D. flabelliforme* (Eichwald), which marks the top of the Cambrian or the base of the Ordovician. Especially the somewhat coarser variety, reproduced in plate 98, figures 2, 3, reminds one strongly of *D. flabelliforme* var. *angelica*. The Mississippian *D. blairi* Gurley is also very similar but has the branches more closely arranged (8–10) and has somewhat thicker branches (0.4 mm.). With larger collections of *D. blairi* Gurley, however, the two may yet prove to be identical.

Occurrence.—Mississippian, Englewood formation, on U. S. Highways 14 and 16, one mile northeast of Deadwood, South Dak.

Types.—Holotype, large imperfect rhabdosome, C. L. 503; paratypes, two fragmentary rhabdosomes, C. L. 502, C. L. 502a.

DICTYONEMA MISSISSIPPIENSE
Ruedemann, n. sp.
Plate 98, figures 4, 5

Rhabdosome of medium size, slender infundibuliform. The holotype, which is incomplete, has a length of 44 mm. and expands from a width of 11 mm. to one of 43 mm. Branches very straight, subparallel, closely arranged, numbering 18 in 10 mm., thin (averaging but 0.1 mm. in width), bifurcating with acute angles at intervals of 8 mm. Dissepiments very thin (0.06 mm.–0.1 mm.), straight transversal or gently convex, about 10 in 10 mm., forming subsquarish meshes about 0.6 mm. wide. Thecae not seen in side view, and bithecae not recognized. From series of thecal apertures it appears that the thecae were arranged in single series as closely as 20 in 10 mm. A branch to the right of the figure is turned sideways and shows the long, slender apertural processes that are expanded distally into platelike terminations, a character also observable in *D. delicatulum* Lapworth.

Remarks.—*D. mississippiense* Ruedemann, n. sp., is characterized by the delicate structure of the rhabdosome, its thin straight branches, which are crowded and connected by numerous very thin dissepiments. It has these characters in common with Silurian and Devonian species such as *D. venustum* Lapworth and *D. delicatulum* Lapworth from the British Silurian and *D. perradiatum* Gurley from the Onondaga limestone of New York. It is, however, not in danger of being confused with any of these, as the first is somewhat coarser in its dimensions, the second is still finer and broadly flabellate in growth, as is also the Onondaga form, which is coarser in structure.

Occurrence.—Mississippian, Englewood formation, on U. S. Highways 14 and 16, one mile northeast of Deadwood, South Dakota.

Types.—Holotype, C. L. 501.

REFERENCE

DARTON, N. H. and PAIGE, SIDNEY, *1925*, Central Black Hills folio, South Dakota: *U. S. Geol. Survey Geol. Atlas Folio* 219.

JOURNAL OF PALEONTOLOGY, VOL. 16, NO. 5, PP. 660–673, 5 TEXT FIGS., SEPTEMBER, 1942

FORAMINIFERAL EVIDENCE FOR THE MIDWAY (PALEOCENE) AGE OF THE CANNONBALL FORMATION IN NORTH DAKOTA

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ABSTRACT—An analysis of 64 species of foraminifera from the Cannonball beds of North Dakota indicates their Midway (Paleocene) age. This supports recent evidence from paleobotany and from vertebrate paleontology but is contrary to the former belief, based on the Cannonball molluscs and corals, that the Cannonball is of late Cretaceous age.

Foraminifera were collected from five localities, four of which are in the upper Cannonball and one in the approximate middle of the formation. The genera represent for the most part moderately shallow water forms. Of the 64 species, 43 are known to occur elsewhere in formations of known age, 13 are new, and 8 are not determinable specifically. Identifications were checked by Mrs. Helen Jeanne Plummer, and the fauna was examined by Dr. Joseph A. Cushman.

Long-distance correlation of the Cannonball foraminifera is necessary because of the absence in the Great Plains of marine faunas younger than the Cannonball and the apparent rarity of foraminifera in the latest marine Cretaceous beds beneath the Cannonball. The fauna is compared with late Cretaceous (Taylor and Navarro) and early Tertiary (Midway, Wilcox, and Claiborne) Gulf Coast assemblages. In correlation, species which are restricted in range in the well-known Gulf Coast section are weighted most heavily.

The new foraminiferal evidence is as follows: 1, More Cannonball species are identical with Midway forms than with Navarro, Wilcox, or Taylor foraminifera. 2, Thirteen Cannonball species are restricted elsewhere to the Midway of the Gulf Coast. Only one species is limited to late Cretaceous formations, and one species to the Wilcox Eocene. 3, Analysis of the known faunas of the Gulf-Coast Taylor, Navarro, Midway, Wilcox, and Claiborne groups shows that only the Midway foraminifera are of Cannonball age. 4, All but one of the 13 Cannonball new species are more closely related to Midway and to Wilcox forms than to Cretaceous species. 5, As in the Midway, two common diagnostic Cretaceous genera are absent from the Cannonball.

INTRODUCTION

EVER SINCE their discovery the Cannonball marine beds have been involved in discussions of the controversial Cretaceous-Tertiary boundary in the northern Great Plains. In the present study microfossils have been used in determining the age of the Cannonball. Foraminifera in abundance were obtained from five localities in the type Cannonball of southern North Dakota during the summers of 1937 and 1940. This paper deals with the stratigraphic significance of the foraminifera; a later report will include the systematic descriptions and the ecologic aspects of the fauna. The investigation was carried on under the auspices of Princeton University and as part of the program of the Yellowstone-Bighorn Research Association.

The writers are indebted to Dr. Joseph A. Cushman and to Mrs. Helen Jeanne Plummer for type material, for valuable suggestions, and for criticism of the manuscript; and to Doctors Erling Dorf, G. L. Jepsen, and B. F. Howell of Princeton University for critical reading of the manuscript. Dr. W. T. Thom, Jr., of Princeton University has been consulted profitably on many field problems. W. R. Barrett, J. W. Bitner, and S. M. Vauclain of Princeton University, and J. H. Powel of Harvard University assisted in the field.

LATE CRETACEOUS-EARLY TERTIARY SEQUENCE IN THE DAKOTAS

Stratigraphic relationships.—The type Cannonball crops out in an irregular belt which extends from Mandan, North Dakota, southwest to the South Fork of Grand River in Perkins County, South Dakota (fig. 1). Typical exposures are in the bluffs of the Cannonball and Heart Rivers in Grant and Morton Counties, North Dakota.

Table 1 shows the late Cretaceous-early

Tertiary sequence in the Cannonball area. Cannonball strata rest upon lignite-bearing beds which, in turn, lie above the terrestrial Hell Creek and the marine Fox Hills and Pierre formations. Paleocene terrestrial "Fort Union" rocks of Tongue River? age overlie the Cannonball. In western North and South Dakota the Cannonball grades laterally into the nonmarine Ludlow, which is the equivalent of the nonmarine Tullock and the middle "Fort Union" (Lebo?) in eastern Montana and Wyoming (Thom and Dobbin, 1924, pp. 492–493). Throughout this succession from the Pierre shale through the "Fort Union" there is no stratigraphic or paleontologic evidence for a major hiatus.

The Pierre and the Fox Hills have always been regarded as late Cretaceous in age, and the post-Cannonball beds in the "Fort Union" have usually been regarded as Paleocene or Eocene. The Cretaceous-Tertiary boundary dispute, therefore, has been focused largely on the beds which occupy the Fox Hills—"Tongue River" interval. Unfortunately, at an early date these strata (the Hell Creek and Tullock and their equivalents) were grouped together as "members" of the "Lance" formation and were tossed about temporally on faunal, floral, and stratigraphic evidence. The writers are of the opinion that the foraminifera indicate Paleocene age for the Cannonball and for its equivalents, the Ludlow and the Tullock.

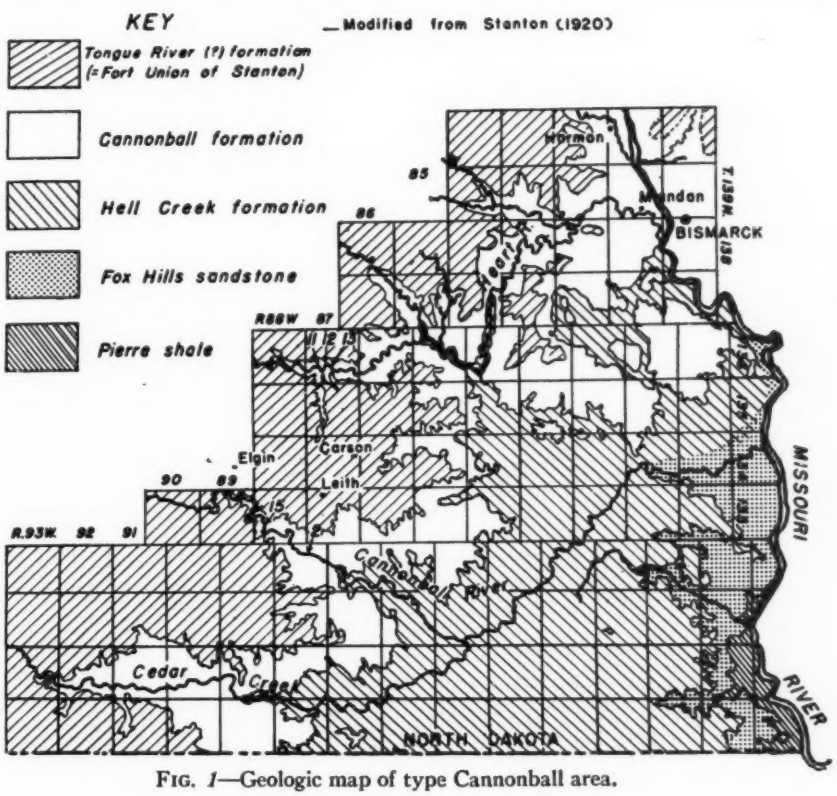

FIG. 1—Geologic map of type Cannonball area.

Pierre shale.—The Pierre formation was originally described by Meek and Hayden (1862, p. 424) as the "Fort Pierre group" comprising 1000 feet of dark-gray marine shale exposed on both sides of Missouri River at Fort Pierre (Wilmarth, 1938, p. 1657). The typical late-Cretaceous fauna of the Pierre contains such well-known forms as *Acanthoscaphites* (*Scaphites*) *nodosus* (Owen), *Baculites compressus* Say, *B. ovatus*

Say, *Inoceramus barabini* Morton, and *Placenticeras whitfieldi* Hyatt. These characteristic late Cretaceous species do not occur in the Cannonball beds, but a few widely ranging molluscs are common to both the Pierre and the Cannonball (Stanton, 1921, p. 11).

In the Cannonball area the upper 400 feet of the Pierre is exposed along the Missouri and Grand rivers (fig. 1), where the Pierre grades upward into the Fox Hills sandstone. The upper 200 feet of the Pierre contains the *Sphenodiscus lenticularis* (Owen) fauna, including *Discoscaphites* (*Scaphites*) *nicolletti* (Morton), *D.* (*Scaphites*) *abyssinus* (Morton), *D.* (*Scaphites*) *cheyennensis* (Owen), and several related species (Stanton, 1921, p. 3). These fossils are not typical of the Pierre but are characteristic of the Fox Hills sandstone farther west. They do not occur in the Cannonball.

Fox Hills sandstone.—Named by Meek and Hayden (1862, p. 427) for exposures "at Fox Hills, between the Cheyenne and Moreau rivers above Fort Pierre," the Fox Hills consists of 25–400 feet of gray, yellow, and buff sandstone and banded shale. Wilmarth recently (1938, p. 767) redefined the type locality as Fox Ridge, in northwest Armstrong and southwest Dewey counties, South Dakota. The exposures in the Cannonball area along the Missouri and Grand rivers (fig. 1) are continuous with the type Fox Hills as redefined by Wilmarth.

The Fox Hills sandstone, a littoral deposit formed in the shallowing waters of the

TABLE 1.—INTERPRETATIONS OF CANNONBALL RELATIONSHIPS

WESTERN DAKOTAS and EASTERN MONTANA						GULF COAST	
Stanton (1921)			Proposed revision (modified after Dorf, 1940)			Present correlation	
Post-Eocene	Several nonmarine formations (Not discussed in present report)		Post-Paleocene	Several nonmarine formations (Not discussed in this report)		Eocene	Jackson group
							Claiborne group
							Wilcox group
Eocene	Fort Union formation		Paleocene	Fort Union group	Tongue River? formation	Paleocene	----?----
Late Cretaceous	Lance formation	Tullock member	Paleocene	Fort Union group	Lebo? formation	Paleocene	Midway group
		Ludlow member			Tullock formation / Ludlow formation		
		Cannonball member			Cannonball formation		
					Lignite-bearing beds		
	Hell Creek member		Late Cretaceous		Hell Creek formation (=Lance formation)		
	Fox Hills sandstone				Fox Hills sandstone	Late Cretaceous	----?---- Navarro group
	Pierre shale				Pierre shale		----?---- Taylor group

Pierre sea, is succeeded conformably by the nonmarine Hell Creek sediments. Variations in the thickness (25–400 feet) of the Fox Hills have been attributed to erosion channels, which are common along the contact with the Hell Creek and within the Fox Hills (Stanton, 1921, p. 4; Thom and Dobbin, 1924, p. 486). These authors agree that there is no evidence of a major hiatus between the Fox Hills and overlying strata.

The Fox Hills is of unquestioned late Cretaceous (latest Montanan) age (Calvert, etc., 1914, p. 13; Stanton, 1921, p. 5; Thom and Dobbin, 1924, p. 485) and is the youngest marine formation in the Great Plains Cretaceous (Dorf, 1940, p. 230). It contains the *Sphenodiscus lenticularis* fauna (Calvert etc., 1914, p. 14; Stanton, 1921, p. 4), which is characteristic of the Fox Hills sandstone at many localities. This same marine molluscan fauna occurs also in the upper 200 feet of the Pierre along the Missouri and Grand rivers in South Dakota (Lloyd and Hares, 1915, p. 527; Stanton, 1921, p. 5). At some localities an irregular sandstone bed at the top of the Fox Hills contains many brackish-water shells mixed with typical species of the *Sphenodiscus* fauna.

Eighteen of approximately 100 Fox Hills invertebrate species occur in the Cannonball beds (Stanton, 1921, p. 11). None of these species common to the Fox Hills and the Cannonball represent diagnostic late Cretaceous groups and few, if any, are restricted Fox Hills forms.

Hell Creek formation.—Barnum Brown (1907, pp. 829–835) originally described the "Hell Creek beds" from exposures of sandstones and somber clays on Hell Creek and nearby tributaries of Missouri River in Garfield County, Montana:

> A fresh-water deposit that is rich in vertebrate fossils, probably continuous with the dinosaur-bearing beds of the Little Missouri and of the Grand and Moreau Rivers (p. 829).

Brown concluded that the Hell Creek was essentially contemporaneous with the late Cretaceous *Ceratops* (Lance Creek) beds of Converse County, Wyoming, on lithologic, vertebrate (*Triceratops*), and invertebrate similarities (p. 844). He separated the Hell Creek from the overlying lower "Fort Union" (Tullock equivalent?) by 100 feet of lignite beds, which he called Fort Union (?) and which Thom and Dobbin later designated as Hell Creek (1924, p. 491).

In the Cannonball area the Hell Creek is from 400 to 500 feet thick (fig. 1). The somber-colored arenaceous shales contain the diagnostic *Triceratops* assemblage of the type Hell Creek (Calvert etc., 1914; Lloyd and Hares, 1915, p. 527; Stanton, 1921, p. 6) and are overlain conformably by lignite-bearing beds, which resemble the Ludlow lithologically, but which have yielded no fossils. The lignite-bearing beds grade upward into the Cannonball marine strata.

Unfortunately, the Hell Creek and the overlying dinosaur-free Tullock (with its Ludlow and Cannonball equivalents in North Dakota) were early grouped together as "members" of the "Lance" formation (Lloyd and Hares, 1915; Stanton, 1921; Rogers and Lee, 1923, p. 20; Thom and Dobbin, 1924, p. 492). In designating the "Lance" as Tertiary? Eocene?, Lloyd and Hares (1915) and Rogers and Lee (1923) were influenced by Knowlton's insistence (1909, p. 181) that the floras of the Hell Creek and the "Fort Union" were identical in character and Eocene. Stanton (1921) also regarded the Hell Creek and the Ludlow-Cannonball strata as members of the "Lance" but insisted that both members were late Cretaceous on invertebrate evidence. Thom and Dobbin (1923), in using the term "Lance" for both Hell Creek and Tullock, did not discuss the age of the beds.

The age relationships of the Hell Creek have been clarified in recent years. The United States Geological Survey in 1935 raised the Hell Creek "member" to formational rank and assigned it to the late Cretaceous (Wilmarth, 1938, p. 1142). After studying the floras of the type Lance and related formations, Dorf (1940, p. 223) stated that many of Knowlton's "Lance" localities represented the dinosaur-free Tullock, Ludlow, or Lebo (middle "Fort Union"). The mixture of species from these localities with those from the type Lance and type Hell Creek compelled Knowlton to describe his "Lance" flora as Eocene "Fort Union" in aspect. Dorf concludes that

> The essential contemporaneity of the type Lance, Hell Creek, Laramie, and Medicine Bow formations is indicated not only by their floral similar-

ity, but also by their stratigraphic positions and their vertebrate and invertebrate faunas. They have in each region yielded characteristic uppermost Cretaceous dinosaurs of the *Triceratops* zone; and they have yielded fresh-water invertebrates of essentially similar aspect.

Thus, on both plant and vertebrate evidence the Hell Creek is clearly established as post-Montanan late Cretaceous in age.

Fort Union group.—In this paper, because of the work of Jepsen (1930, p. 463), Simpson (1937, p. 20), and Dorf (1940, pp. 213–236), and because of the foraminiferal evidence presented herewith, the base of the Paleocene "Fort Union" group is regarded as the marine Cannonball and its nonmarine equivalents, Ludlow and Tullock, to the west. The type Tullock is overlain by terrestrial beds, the upper portion of which represents type Tongue River (Taff, 1907, p. 128) in central-eastern Montana and the lower portion of which is equivalent not only to the upper Ludlow and Cannonball but may well represent the Lebo (Thom and Dobbin, 1924, p. 492). The type Ludlow is overlain in western North Dakota by type Fort Union (Meek and Hayden, 1862, p. 433), which, although separated geographically from the type of the Tongue River, has yielded a single mammalian fossil of post-Lebo (probably Tongue River) age (Jepsen, 1940, p. 242). The Fort Union exposures that occur above the type Cannonball are continuous with those of the type area and presumably are of the same age. It is unfortunate that the "Fort Union" group has embraced two "formations," the Lebo and the Tongue River, whose type areas are geographically separated from each other as well as from that of the group to which they belong.

The present inclusion of the Cannonball in the "Fort Union" follows the conception that the composite "Fort Union" includes the entire Paleocene series (Jepsen, 1930, p. 496; Simpson, 1937, p. 21).

The Tullock and the Ludlow nonmarine formations were each first described as the upper member of the "Lance" formation in east-central Montana and western North Dakota respectively (Rogers and Lee, 1923, p. 29; Lloyd and Hares, 1915, p. 528). However, both the Tullock and the Ludlow are more easily distinguishable lithologically from the underlying "somber clays" of the Hell Creek than from the overlying light-brown sandstones and shales of the "Fort Union" (Winchester, Hares, Lloyd, and Parks, 1916, p. 20; Rogers and Lee, 1923, p. 11, 29). The close relationship of the Ludlow to the "Fort Union" was also suggested by Thom and Dobbin, who indicated the western interfingering of the upper Ludlow with beds reported as representing the Lebo (middle Paleocene) member of the Fort Union (1924, p. 492). Although these so-called Lebo strata are stratigraphically higher than the type Tullock (which they overlie) and occupy a position within the "Fort Union," they cannot be traced into the type Lebo in the Crazy Mountains, Montana. The Ludlow is overlain by type Fort Union, which is generally regarded as post-Lebo and probably Tongue River in age (Jepsen, 1940; p. 247).

Faunal and floral studies of the Tullock and the Ludlow have brought varied results. Rogers and Lee (1923, p. 29) placed the Tullock in the Tertiary? Eocene? largely because of a single bone fragment of a ceratopsian[1] which indicated "Lance" and therefore Tertiary? age. They regarded the Tullock plants as the same as those in both the underlying lower Lance (Hell Creek) and in the overlying Lebo, and, therefore, of no stratigraphic value. Lloyd and Hares (1915, p. 528) designated the Ludlow as Eocene? largely because of its inclusion at that time in the "Lance." Stanton (1921, p. 6) recognized the Fort Union character of the Ludlow flora, but called the Ludlow Cretaceous because of its interfingering with the Cannonball. Regarding the age of the dinosaur-free Tullock and Ludlow, Wilmarth (1938, p. 1142, 1234) stated that the United States Geological Survey now classifies the Tullock as late Cretaceous or Eocene and the Ludlow as late Cretaceous.

Vertebrate paleontologists (Brown, 1914, p. 356; Simpson, 1929, p. 6, 1937, p. 20; Jepsen, 1930, p. 463, 475) have concurred in limiting the true Lance and the Hell Creek to the *Triceratops* zone and in designating the type Tullock and its dinosaur-

[1] Bone fragment found on the surface of a steep slope about 50 feet above the base of the Tullock and identified by Gilmore (Rogers and Lee, 1923, p. 34) as belonging probably to *Triceratops*.

free equivalents as Paleocene ("Fort Union") in age.

Recent studies of the type Tullock and the type Ludlow floras by Dorf (1940, p. 223) clearly indicate that

> These beds and their equivalents are younger than the true Lance (Hell Creek) formation and not part of it and are both stratigraphically and paleontologically related more closely to the beds of the overlying "Fort Union"

On paleobotanical evidence, therefore, the Cretaceous-Paleocene boundary is now placed at the apparently transitional contact between the Hell Creek and the overlying Tullock and its dinosaur-free equivalents (Ludlow and Cannonball).

Thus, present evidence based on plant, vertebrate, and stratigraphic data, indicates Paleocene age for the apparent Cannonball equivalents in western North Dakota and eastern Montana.

LATE CRETACEOUS-EARLY TERTIARY SEQUENCE IN THE GULF COAST

As shown in Table 1, the Taylor (Wilmarth, 1938, p. 2120) and Navarro (Wilmarth, 1938, p. 1467) groups represent the latest Cretaceous in the Gulf Coast. Taylor and Navarro sediments are marine in origin and contain diagnostic late Cretaceous index species.

The Midway group is Paleocene in age (Gardner, 1941, pp. 644–649) and rests unconformably on the underlying Cretaceous (Stephenson, 1915; 1941). Wilcox Eocene beds (Wilmarth, 1938, p. 2333) overlie the Midway and are succeeded by Claiborne Eocene (Wilmarth, 1938, p. 448) and Jackson strata (Wilmarth, 1938, p. 1035). These Tertiary groups, with the exception of the Wilcox, are largely marine and are each characterized by distinctive foraminiferal and molluscan faunas.

CANNONBALL FORMATION

The Cannonball was first described (Lloyd, 1912) as the "marine member of the Lance formation" from exposures in the bluffs of the Cannonball and Heart rivers, North Dakota. The writers here regard Lloyd's Cannonball beds as a formation. The 250–300 feet of dark sandy shales and shaly sandstones grade above into the nonmarine "Fort Union" (Tongue River?) and below into lignite-bearing beds (Ludlow?) which overlie the Hell Creek. The irregular belt of outcrops extending southwest from Bismarck is shown in figure 1. Throughout the type area the beds are essentially flat lying. Although meander scarps afford many excellent exposures, beds cannot be traced easily from outcrop to outcrop.

Evaluation of the Cannonball fauna has been difficult because of the absence in the Great Plains of marine faunas younger than the Cannonball assemblage.[2] Without detailed fossil evidence, Lloyd originally (1912) designated the Cannonball as Eocene? in age because of its inclusion in the "Lance." All later age determinations of the Cannonball, with the exception of Stanton's, have been based on studies of strata adjacent to the Cannonball.

Stanton (1921) upheld the Cretaceous age of the Cannonball molluscan fauna. Thom and Dobbin (1924, p. 494) suggested correlation of the Lebo (middle Paleocene) with the upper part of the Ludlow, which interfingers to the east with the upper Cannonball. Dorf (1940, p. 231) has insisted that the fossil plants in the Ludlow and Tullock equivalents of the Cannonball are Paleocene. On vertebrate evidence, Jepsen has recently (1940, p. 243) expressed the opinion that

> Through a series of largely unproved possibilities, the Cannonball may be correlated, in part at least

with the Lebo, the Lebo with the Torrejon (middle Paleocene), and the Torrejon with the Midway (Paleocene of Texas).

In referring the Cannonball invertebrates to the late Cretaceous, Stanton (1921, pp. 11–13) states:

> Of the 60 molluscan forms, 33 are described as new and 27 are identified with previously described forms . . . its [the Cannonball fauna's] close relationship with the Cretaceous is shown by the fact that 24 of its species (40 per cent of its known molluscan fauna) are identified with species found in the late Cretaceous formations (Pierre and Fox Hills) of the same general region, and 18 of the species (30 per cent) are known in the Fox Hills fauna.

As further evidence he uses (p. 18) the questionable argument that because the Cannonball is exposed in the midst of wide-

[2] The nearest exposures of early Tertiary marine beds are in the Gulf Coast (Midway and Wilcox groups).

spread Cretaceous deposits, a thousand miles from the nearest marine Eocene, the Cannonball is more closely "connected with the Cretaceous rather than the Eocene."

The writers' view that the Cannonball is Paleocene is supported by much of Stanton's evidence (p. 13). He admits, for example, that

> The Cannonball fauna has the general aspect of a Tertiary fauna on account of the absence of most of the exclusively Mesozoic types [index ammonites, belemnites, and such pelecypods as *Inoceramus*] and the preponderance of long-lived modern types (p. 13).

It is significant, too, that the faunas of the Cannonball and the Gulf Coast early Tertiary formations have a large proportion of genera in common (Stanton, p. 13), larger than either has with the latest Cretaceous. Furthermore, at least five Cannonball molluscan species are similar to, or identical with, early Tertiary Midway and Wilcox Gulf Coast forms (Stanton, p. 13). Two Cannonball genera, *Calyptraphorus* and *Cylichnella*, are not known to occur in pre-Paleocene faunas in the Americas (p. 13).

In analyzing the results obtained by Stanton it is necessary to point out that, because of poor preservation or rarity, 8 of the 24 molluscs listed as common to the Cannonball and to the Cretaceous were doubtfully or tentatively identified: *Nucula subplana* Meek and Hayden?—"doubtfully referred" (p. 20); *Yoldia scitula* Meek and Hayden—"surface sculpture is not perfectly preserved" (p. 21); *Cucullaea shumardi* Meek and Hayden—represented by a cast of the right valve with "a small portion of the shell" (p. 22); *Cucullaea nebrascensis* Owen?—"Two small, fragmentary specimens . . . probably represent young individuals of *C. nebrascensis*" (p. 22); *Panope simulatrix* Whiteaves?—"Neither the hinge nor the pallial line has been seen on the new specimens found in the Cannonball member . . . tentatively referred" (p. 32); *Dentalium pauperculum* Meek and Hayden—"Not a typical *Dentalium* . . . not well enough preserved to justify its reference to any of the described subgenera . . ." (p. 34); *Cylichna scitula* Meek and Hayden—"tentatively referred to that species, though it is distorted by pressure and its true generic character is not determinable" (p. 48); and *Pyrifusus newberryi* (Meek and Hayden)—"the few imperfect and immature specimens referred to the species are similar in form and sculpture . . ." (p. 41).

If these eight species are disregarded as of doubtful status, only 16 Cannonball species (26 per cent of the fauna) are identical with forms occurring in the Cretaceous, and only 11 species (18 per cent) are similar to Fox Hills forms. Even if the 8 molluscan species are included in correlation, so that 30 per cent of the Cannonball species occur in the Fox Hills, it is significant that an even greater proportion (32 per cent) of the Cannonball foraminifera (p. 668) occur also in the uppermost Cretaceous (Navarro of Texas). However, a much greater proportion (59 per cent) of the Cannonball foraminifera occurs also in the Gulf Coast Midway; since many of these are restricted to the Midway and none to the Navarro, the strong Paleocene aspect of the Cannonball foraminifera is evident (p. 668). Correlation entirely by percentage of identical species can often be misleading, particularly when, as is the case with the Cannonball molluscs, faunas younger than those under study are not available in the same general region, and when comparisons are not based on restricted species or diagnostic index groups. The Cannonball molluscs have, of necessity, been compared only with the older formations in the Great Plains area, whereas the foraminifera have been studied in relation to the entire late Cretaceous-early Tertiary sequence on the Gulf Coast. Furthermore, none of the Fox Hills Cretaceous index groups (ammonites, belemnites) occurs in the Cannonball, and the species common to the Fox Hills and the Cannonball belong to genera more characteristic of the Tertiary than the Cretaceous. In the words of Meek and Hayden (1857, p. 13):

> Many of the [Fox Hills] species approximate so closely to Tertiary forms that did we not find them everywhere associated with *Ammonites*, *Scaphites*, and other genera which are known not to have existed later than the Cretaceous epoch, we should at once pronounce the formation in which they occur Tertiary.

In view of all the evidence produced by Stanton the writers are of the opinion that the Cannonball molluscs have as definite Tertiary affinities as do the foraminifera. It

seems likely that re-examination of the Cannonball molluscan fauna and comparison of the molluscs with more recently described Paleocene and Eocene forms than was possible in 1920, should indicate stronger Paleocene relationships than did the original study.

The possibility that the Cannonball is Paleocene has already been suggested by Stephenson and Reeside (1938, p. 1636):

> A still higher marine zone of small extent (Cannonball) has been considered Cretaceous but may well be basal Eocene (Paleocene of European section).

represent the upper part and one the approximate middle of the formation. As yet, the lower beds of the Cannonball have yielded no foraminifera.

As shown in figure 2, the known Cannonball foraminiferal fauna comprises 64 forms, of which 13 (20 per cent) are new and 8 (13 per cent) are not determinable specifically. At present, 43 species are known to occur elsewhere in formations of known age. Of these forms with outside distribution, 21 are long-range species and 22 (34 per cent of the known fauna) are species restricted in geologic range on the Gulf Coast.

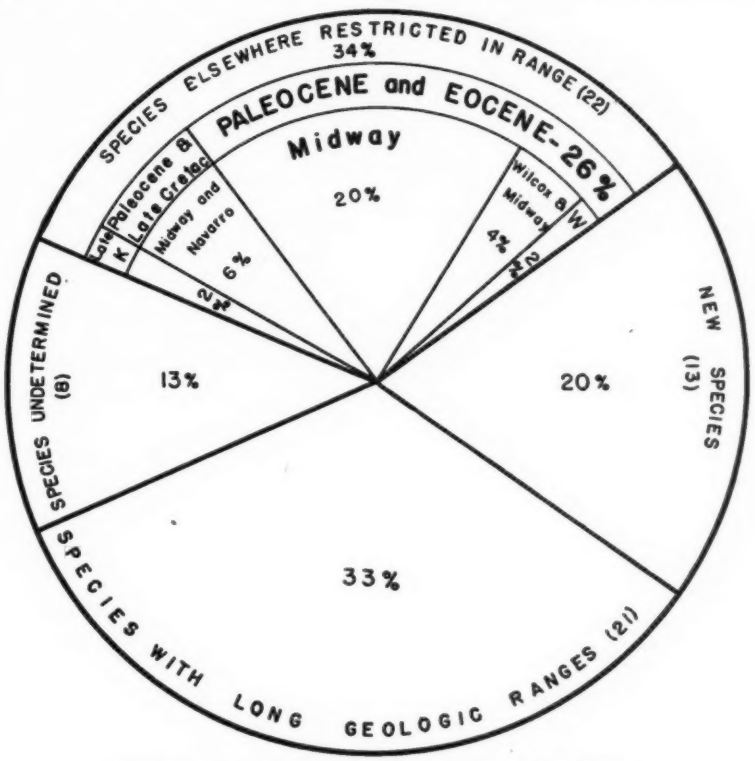

FIG. 2—Percentage composition of Cannonball fauna.

FORAMINIFERA OF THE TYPE CANNONBALL

General character.—The type Cannonball foraminifera discussed in this report were collected from five localities,[3] four of which

The Cannonball genera represent, for the

[3] Locality 2: Middle Cannonball. Gully on north side, North Fork of Cannonball River, NW. ¼ sec. 11, T. 132 N., R. 88 W. Locality 11: Upper Cannonball. South bank of Heart River, W. ½ sec. 29, T. 136 N., R. 87 W. Locality 12: Upper Cannonball. North bank of Heart River, SW. ¼ sec. 21, T. 136 N., R. 87 W. Locality 13: Upper Cannonball. North bank of Heart River, NE. ¼ sec. 28, T. 136 N., R. 87 W. Locality 15: Upper Cannonball. East bank of North Fork of Cannonball River, NW. ¼, SW. ¼, sec. 20, T. 133 N., R. 88 W.

most part, common, moderately shallow water forms, which also characterize the Gulf Coast early Tertiary. The relative abundance of the Lagenidae and the Rotaliidae and the scarcity of the Textulariidae and the genus *Globigerina*, in both the Cannonball and the earliest Tertiary Gulf Coast formations, indicate essentially similar ecological conditions in the two areas. The Cannonball fauna is characterized also by the presence of only two arenaceous species and by the large number of individuals of the genus *Bulimina*.

No attempt is made at this time to establish faunal zones within the Cannonball. The assemblage from the single locality in the middle of the formation can be recognized by (1) the presence of a new species of *Bulimina* and (2) the absence of many of the large species of the Lagenidae that are so distinctive of the upper beds. However, it seems wise to consider the Cannonball fauna as a unit, at least until more material can be obtained from the potential zone in the middle of the Cannonball.

In correlation, comparison of the Cannonball fauna with other faunas of known age is based chiefly on the 43 species with outside distribution. Particular emphasis is placed on Cannonball forms that are elsewhere restricted in geologic range.

Long-range correlation of the Cannonball fauna is necessary because of the absence of marine faunas above the Cannonball, the apparent scarcity of foraminifera in the youngest marine formation[4] (Fox Hills) below the Cannonball, and the great distance from any known faunas of similar age. Accordingly, comparisons are made directly with the well-known but distant Gulf Coast late Cretaceous and early Tertiary faunas (table 1), without the advantages of examining assemblages in intervening areas.

Relationship to Gulf Coast late Cretaceous and early Tertiary faunas.—In considering the 43 Cannonball species that are identical with Gulf Coast forms (fig. 3), it is significant that 38 occur in the Midway group, while 21 appear in the late Cretaceous, the Navarro formation, and 24 are known in the Wilcox Eocene group. Only 16 Cannonball species are present in pre-Navarro Cretaceous strata, and only 17 have been reported in post-Wilcox beds. Expressed in tabular form the number of Cannonball species occurring in Gulf Coast formations is as follows:

	Percentage of 43 species with outside distribution	Percentage of entire Cannonball fauna (64 species)
Post-Wilcox, 17 spp...	39	26
Wilcox, 24 spp.....	56	37
Midway, 38 spp.....	88	59
Navarro, 21 spp.....	49	32
Pre-Navarro Cretaceous, 16 spp.....	37	25

Although correlation based largely on the percentage of identical species may often be misleading (p. 666), the large proportion of Cannonball species that are identical with Midway forms is significant.

Of the 38 Cannonball species that occur in the Midway (fig. 3), 13 have been known heretofore only from the Midway. These species are diagnostic Midway index forms. Only one Cannonball species has previously been restricted to the late Cretaceous; this rare and variable form, *Nonionella* cf. *N. robusta* (Plummer), occurs in both the Taylor and Navarro groups. Furthermore, only one of the Cannonball species occurring also in post-Midway Tertiary formations has heretofore been limited to post-Midway beds (*Guttulina* cf. *G. wilcoxensis* Cushman and Ponton, to the Wilcox).

As expressed diagrammatically in figure 4, further analysis of the 43 foraminifera with outside distribution reveals 21 species or 48.8 per cent with long geologic ranges and 22 index species (51.2 per cent) limited in geologic range on the Gulf Coast. The Tertiary aspect of the Cannonball foraminifera is indicated by the fact that 40 per cent (17) of the species with outside distribution are not known in pre-Tertiary rocks and are restricted to the Paleocene and the Eocene; 9.3 per cent (4) are restricted to the Paleocene and the late Cretaceous, and only 2.3

[4] A few foraminifera from the upper Pierre and from the Fox Hills have been examined by the writers. Such characteristic late Cretaceous Gulf Coast species as *Lenticulina navarroensis* (Plummer) *Haplophragmoides excavata* Cushman and Waters, *H. rugosa* Cushman and Waters, and *H. glabra* Cushman and Waters have been noted. These species do not occur in the Cannonball. The Pierre and Fox Hills have not yielded any typical Midway forms.

per cent (1) to the late Cretaceous. The close relationship between the Cannonball and the Midway faunas is shown by the restriction to the Midway of 30.2 per cent of the 43 Cannonball foraminifera which are known elsewhere.

One species restricted to the Wilcox (2 per cent):

Guttulina cf. wilcoxensis Cushman and Ponton.

Three species restricted to the Midway and Wilcox (6.9 per cent):

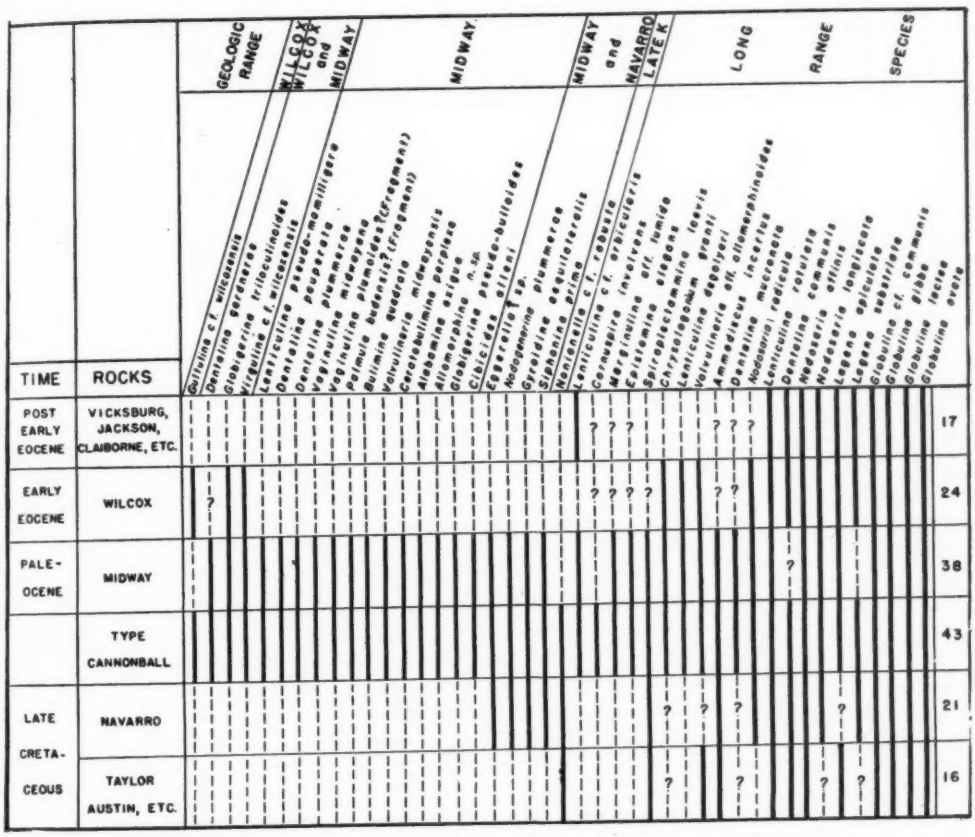

FIG. 3—Relationship of type Cannonball foraminifera to Gulf Coast late Cretaceous and Tertiary faunas.

Ten of the 13 Cannonball foraminifera that are Midway index species are common or abundant in the Cannonball material. One of the remaining three forms, *Vaginulina midwayana* Fox and Ross, new name, is represented by only three specimens; two species, *Vaginulina plumoides* Plummer? and *Palmula budensis* (Hantken)?, have been identified from fragments of single specimens. Each of these three rare but significant species has been checked by Mrs. Helen Jeanne Plummer.

Dentalina gardnerae (Plummer).
Globigerina triloculinoides Plummer.
Virgulina cf. wilcoxensis Cushman and Ponton.

Thirteen species restricted to the Midway (30.2 per cent):

Lenticulina pseudo-mamilligera (Plummer).
Dentalina pauperata d'Orbigny.
Dentalina plummerae Cushman.
Vaginulina midwayana Fox and Ross, n. name.[5]

[5] *Vaginulina midwayana* is proposed for *V. robusta* Plummer, which, Mrs. Plummer has pointed out, is a homonym of *Vaginulina truncata* Reuss var. *robusta* Chapman (not Berthelin and Chap-

Vaginulina plumoides? Plummer (fragment).
Palmula budensis (Hantken)? (fragment).
Bulimina quadrata Plummer.
Valvulineria midwayensis (Plummer).
Ceratobulimina perplexa (Plummer).
Alabamina exigua (H. B. Brady).
Allomorphina n. sp.[6]
Eggerella? sp.
Nodogenerina plummerae (Cushman).
Gyroidina aequilateralis (Plummer).
Siphonina prima Plummer.

One species restricted to late Cretaceous (2 per cent):

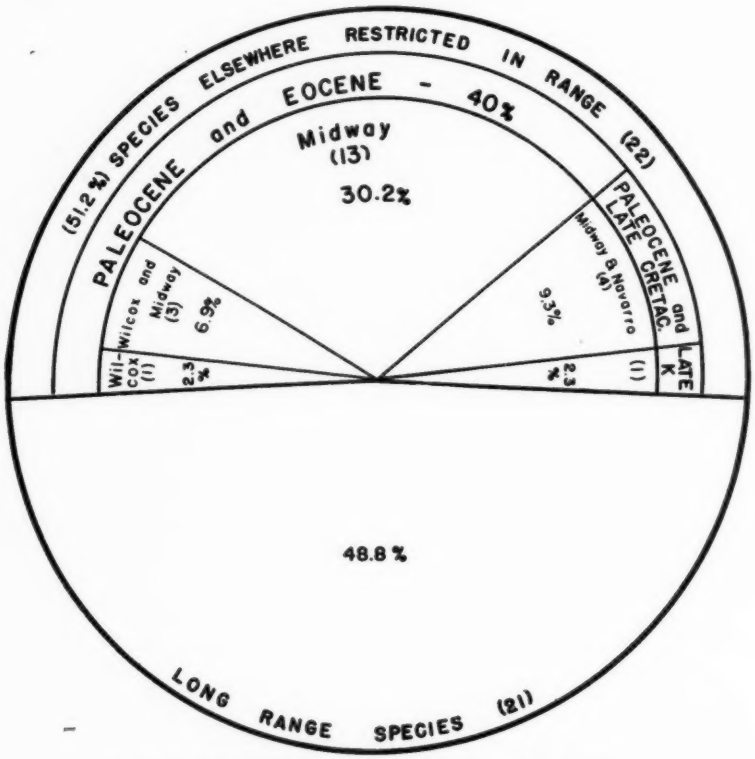
(51.2 %) SPECIES ELSEWHERE RESTRICTED IN RANGE (22)
PALEOCENE and EOCENE - 40%
Midway (13) 30.2%
Wil-cox (1) 2.3 %
Wilcox and Midway (3) 6.9%
Midway & Navarro (4) 9.3%
PALEOCENE and LATE CRETAC. (1) 2.3 %
LATE K
48.8 %
LONG RANGE SPECIES (21)

FIG. 4—Cannonball species with outside distribution.

Globigerina pseudo-bulloides Plummer.
Cibicides alleni (Plummer).

Four species restricted to Paleocene and late Cretaceous (9.3 per cent):

Nonionella cf. robusta (Plummer).

Twenty-one species with long geologic ranges:

Ammodiscus incertus (d'Orbigny).
Spiroplectammina laevis (Roemer).
Cornuspira involvens (Reuss).
Lenticulina degolyeri (Plummer).
Lenticulina cf. orbicularis (d'Orbigny).
Lenticulina rotulata Lamarck.
Marginulina aff. tumida Reuss.
Dentalina communis d'Orbigny.
Dentalina mucronata Neugeboren.
Nodosaria affinis d'Orbigny.
Nodosaria longiscata d'Orbigny.
Chrysalogonium granti (Plummer).
Nodosaria radicula (Linnaeus).
Lagena apiculata (Reuss).
Lagena substriata Williamson.
Globulina cf. communis (d'Orbigny).

man), Royal Jour. Mic. Soc., p. 424, pl. 8, fig. 7, 1894; p. 14, pl. 2, fig. 13, 1898.

[6] The Cannonball forms included in this species are identical with Texas Midway specimens referred by Mrs. Plummer (1926, p. 129) to *Allomorphina trigona* Reuss. The test of the new species is distinguished from *A. trigona* Reuss and from other Cretaceous species by the three broadly rounded angles and an unusually large final chamber. The type locality is Mrs. Plummer's Station 85 (1926, p. 62) where the form is abundant. Specimens supplied by Mrs. Plummer from this locality will be used in describing the new species in a later report.

Globulina gibba (d'Orbigny).
Globulina lactea (Walker and Jacob).
Globulina ovata (d'Orbigny).
Valvulineria aff. allomorphinoides (Reuss).
Epistomina elegans d'Orbigny.

The absence in the Cannonball fauna of the typically Upper Cretaceous genus *Globotruncana* and of striate forms of the genus *Gümbelina* weighs against the late Cretaceous age of the Cannonball. According to Mrs. Plummer,[7] some exposures of late Cretaceous beds in the Gulf Coast lack these genera, but such strata are incidental in a section generally well characterized by these groups of tests. Furthermore Cretaceous beds in the Gulf Coast do not yield the characteristic Midway assemblage. The relative abundance of the Lagenidae and the Rotaliidae in the earliest Tertiary Gulf Coast strata (Plummer, 1926, p. 35; Cushman, 1940) and in the Cannonball, indicates more the essential similarity of ecologic conditions in the two areas than any other age relationship.

Twelve of the 13 new species (to be described in a later report) are comparable to Tertiary rather than to late Cretaceous forms; one new species of *Bulimina* resembles *Bulimina trihedra* Cushman from the Velasco (late Cretaceous) shale of Mexico.

Regarding the relationship of Cannonball Foraminifera to Gulf Coast faunas Mrs. Plummer writes,[8]

> Considering the distance of the northern Great Plains from the Gulf Coast, the large proportion of the Cannonball foraminiferal species that are identical with restricted Midway species must make your conclusions of Paleocene age for the Cannonball incontrovertible. Further it seems to point very strongly to northward continuity of the Midway sea over a broader expanse of the states between than has hitherto been suggested. Undoubtedly more modern treatment of the larger fossils in both the late Cretaceous and early Tertiary strata in the section including the Cannonball will confirm your conclusions.

Relationships of Gulf Coast faunas to type Cannonball Foraminfera.—In analyzing the known faunas of the late Cretaceous and early Tertiary Gulf Coast formations, the similarity of the Midway and Cannonball assemblages is again apparent. Only the Midway fauna is Cannonball in age. The relationships are shown diagrammatically in figure 5.

Approximately 116 species have been described from Gulf Coast Midway strata. Thirty-nine of these species (34 per cent) occur also in the Cannonball. Furthermore, 44 of the 116 Midway species are restricted to the Midway, and 13, or 30 per cent of these Midway index forms, are present in the Cannonball.

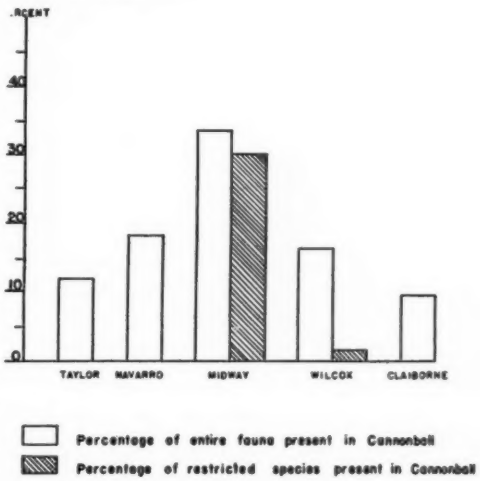

FIG. 5—Percentage of Gulf Coast species in the Cannonball.

The known Wilcox fauna comprises about 161 species. Cannonball localities have yielded 25 (16 per cent) of these forms. However, only 1 species (2 per cent of the 51 diagnostic index Wilcox Foraminifera) has appeared in the Cannonball samples.

Claiborne species total nearly 200. Only 17 (8 per cent) of these occur in the Cannonball, and no species limited in range to the Claiborne group have been identified from the Cannonball.

Gulf Coast faunas older than the Midway assemblage show poor correlation with the Cannonball Foraminifera. Only 21 (18 per cent) of a total of 119 Navarro species have been reported in the Cannonball, and no Navarro index species have been noted in the Cannonball. The Taylor group, which underlies the Navarro, shows even more remote relationship to the Cannonball. While 16 (12 per cent) of 130 Taylor species have been identified with Cannonball forms, the

[7] Personal communication, 1940.
[8] Personal communication, 1941.

Cannonball fauna does not include any Foraminifera that are restricted to the Taylor on the Gulf Coast.

In the entire Gulf Coast stratigraphic section from the Taylor to the Claiborne, the Midway fauna alone is Cannonball in age on the basis of number of identical species and the number of restricted Midway forms present in the Cannonball. The resemblance of other Gulf Coast faunas to the Cannonball forminifera diminishes immediately below and immediately above the Midway.

Age of the Midway.—In designating the Cannonball as Paleocene in age because of faunal similarity with the Midway, the writers are aware that the Paleocene age reference for the Midway has been challenged. Scott (1941, p. 2006) has suggested that the Midway is Cretaceous because:

> Midway lithology is more similar to underlying Navarro than to overlying nonmarine Wilcox . . . Midway depositional history [is] closely comparable to that of the Danian in Scandinavia,

and Midway molluscan species of *Hercoglossa* and *Venericardia* indicate Danian (latest Cretaceous) age.

With this exception, stratigraphic and invertebrate studies supported by mammalian evidence seem to indicate that the Midway is Tertiary. As in the Cannonball, ammonites and belemnites do not occur in Midway beds (Stephenson, 1914, p. 158). Furthermore, no single molluscan species in the Gulf Province ranges from Navarro into Midway strata, whereas the presence in the Midway of genera not known below the Tertiary relates the Midway more to the overlying Wilcox than to the Navarro (Gardner, 1933; 1941, pp. 644–649).

Stephenson (1914; 1941) has demonstrated the presence of a widespread unconformity of considerable magnitude between the Midway and underlying Cretaceous beds. Nevertheless, the similarity in some localities of the sediments below and above the Navarro-Midway contact might suggest that the importance of the Navarro-Midway hiatus should be minimized. However, as pointed out by Stephenson (1941, p. 642):

> Actually the presence of such totally different assemblages of fossil species in similar sediments on opposite sides of a stratigraphic break is a strong argument in favor of the importance of that break.

Mammalian remains can be tentatively evaluated as an aid in dating the Midway (Jepsen, 1940, p. 243). If the specimen of *Anisonchus fortunatus*, described by Simpson (1932) from a deep Louisiana well, came from the Midway, as seems likely, the vertebrate evidence supports the conclusions based on invertebrates. *Anisonchus* is particularly characteristic of Torrejonian time and Simpson (1932, p. 4) states that *A. fortunatus* "seems to be of approximately middle Paleocene, Torrejon age."

In view of all the evidence, both faunal and stratigraphic, it seems certain that the Midway must be regarded as Paleocene and not Cretaceous in age. In fact, correlation of the Midway with the Cannonball, which has already been proved Paleocene on plant and vertebrate data, is in itself good evidence for Paleocene age of both the Midway and the Cannonball.

CONCLUSIONS

1. The type Cannonball marine beds are Midway (Paleocene) in age on the basis of an analysis of 64 species of Foraminifera:
   a. Thirty-eight of 43 Cannonball species with outside distribution are identical with Gulf Coast Midway forms. Only 21 Cannonball species occur in the Navarro Cretaceous group and only 24 in the Wilcox Eocene group.
   b. Thirteen Cannonball species are restricted to the Midway on the Gulf Coast, three species to the Midway and the Eocene Wilcox, one species to the Wilcox, and one species to the late Cretaceous Taylor and Navarro.
   c. As in the Gulf Coast Midway, such typically Cretaceous genera as *Globotruncana* and striate forms of *Gümbelina* are absent from the Cannonball.

2. Analysis of the known faunas of late Cretaceous and early Tertiary Gulf-Coast formations indicates that the Midway alone is Cannonball in age. Thirteen of 44 Midway index species occur in the Cannonball, whereas only one Wilcox index species is present in the Cannonball; no diagnostic Navarro, Taylor, or Claiborne forms have been observed in the Cannonball assemblage.

3. The foraminiferal evidence supports recently expressed conclusions, based on

plant, vertebrate, and stratigraphic evidence in adjacent Great Plains formations, that the Cannonball is Paleocene. The Cannonball molluscs, described by Stanton, do not contradict the other evidence.

4. Correlation of the Midway with the Cannonball, which has been designated Paleocene on plant and vertebrate data, strengthens other lines of evidence that the Midway is Paleocene and not late Cretaceous.

5. The suggested relationships of the Cannonball to adjacent strata and to Gulf Coast formations are summarized in table 1.

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PALEONTOLOGICAL NOTES

SUBSTITUTES FOR MOLLUSCAN HOMONYMS

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SUBSTITUTIONS are here offered for four homonyms used in my monograph on "The Claibornian Scaphopoda, Gastropoda and dibranchiate Cephalopoda of the southern United States." published in 1937 as volume 7, number 32, of the Bulletins of American Paleontology.

Genus PUNCTURELLA Lowe, 1827
Subgenus FISSURISEPTA Seguenza, 1863
Section ALTRIX Palmer, n. name

Folia PALMER, *1937*, Bull. Am. Paleontology, vol. 7, no. 32, p. 30.
Not *Folia* LOHMANN, *1892*, Ergebnisse Plankton-Exped., Band 1, p. 139; Band 2, E, c, p. 81. *Fide* NEAVE, Nomenclator Zoologicus, vol. 2, p. 414; Zoöl. Record, 1892, p. 7. (Tunicata.)
Not *Folia* MAYER, *1912*, Carnegie Inst. Washington Pub. 162, p. 46. (Coelenterata.)

Genus TEXMELANATRIA Palmer, n. name

Texania PALMER, *1937*, Bull. Am. Paleontology, vol. 7, no. 32, p. 181.
Not *Texania* CASEY, *1909*, Washington Acad. Sci. Proc., vol. 11, p. 84. (Coleoptera.)

Genus TEREBRA Bruguière, 1789
Subgenus MIRULA Palmer, n. name

Terebrella PALMER, *1937*, Bull. Am. Paleontology, vol. 7, no. 32, p. 466.
Not *Terebrella* PACKARD, *1867*, Boston Soc. Nat. History Mem., vol. 1 (2), p. 292. (Vermes. Typographical error for *Terebella* Linné.)
Not *Terebrella* MALTZAN, *1886*, Deutsche mal. Gesell. Nachrichtsbl. (Frankfort), vol. 18, p. 27. *Fide* NEAVE, Nomenclator Zoologicus, vol. 4, p. 426; Zoöl. Record, 1886, p. 73. (Mollusca.)
Not *Terebrella* ANDREAE, *1887*, Geol. Specialkarte Elsass-Lothringen Abh., Band 4, Heft 3, p. 32. (Mollusca.)

Genus NATICA Scopoli, 1777
Subgenus NATICARIUS Duméril, 1805
Section TELLA Palmer, n. name

Natella PALMER, *1937*, Bull. Am. Paleontology, vol. 7, no. 32, p. 112.
Not *Natella* WATSON, *1934*, Mal. Soc. London Proc., vol. 21, pp. 150, 160. (Mollusca.)

Dr. Harald A. Rehder, of the United States National Museum, kindly called my attention to the preoccupation of *Natella*.

EUSTEPHANELLA, NEW NAME FOR EUSTEPHANUS SWARTZ AND SWAIN

F. M. SWARTZ and F. M. SWAIN
Pennsylvania State College and University of Kansas

ALLEN F. AGNEW of the Illinois Geological Survey has called to our attention the fact that the name *Eustephanus* applied by us (1941, Geol. Soc. America Bull., vol. 52, p. 435) to an ostracode genus is a junior homonym of *Eustephanus* Reichenbach, 1849. We here propose *Eustephanella* to replace *Eustephanus* Swartz and Swain, 1941.

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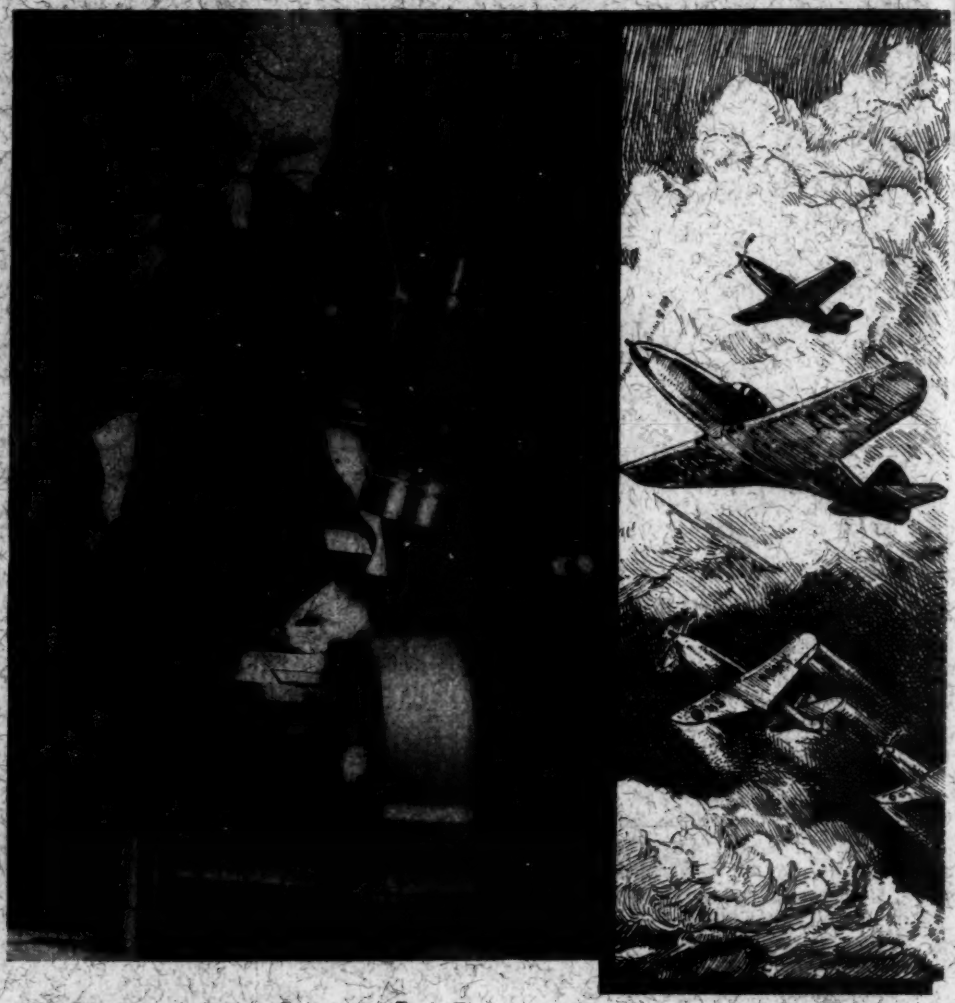

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